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The Journal of
THE ROYAL AERONAUTICAL SOCIETY

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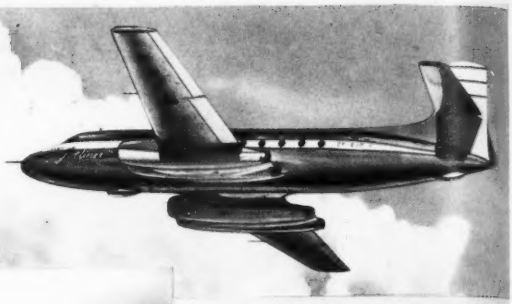

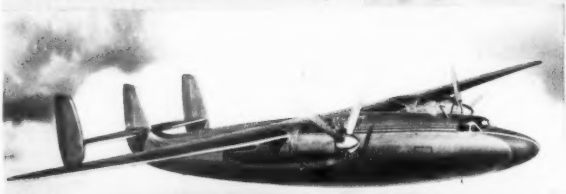

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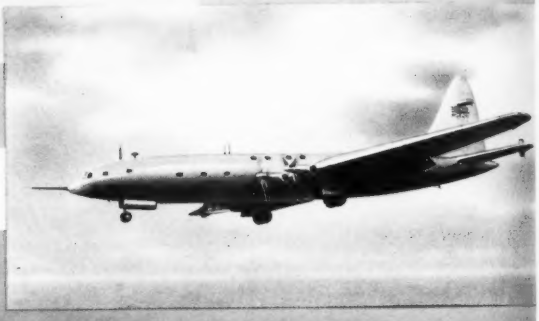

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THE ROYAL AERONAUTICAL SOCIETY

GRADUATE AND STUDENT SECTION

February 1950.

THE HIGH-PERFORMANCE GLIDER

By F. G. IRVING, B.Eng., D.I.C., Grad.R.Ae.S.

Although allowance must be made for the effects of the war, no glider has yet been made in this country with a performance better than the German "Weihe" of about 13 years ago. The "Weihe" has a profile drag coefficient of 0.016, and uses a Gottingen 549 wing section. In these days of low drag sections, it should be possible to improve that figure, and by cleaning up the wing-fuselage junction, deleting external aileron horns and so forth, something of the order of 0.012 should be feasible.

A logical design procedure would then be to aim for the best mean cross-country speed for some chosen "average thermal strength." How strong? Probably, for this country, not more than 5 ft./sec. true, assuming, say, 0.5 ft./sec. "down-draught" between thermals. Proceeding in the manner explained by K. G. Wilkinson in his lecture to the Section*, the optimum wing loading for these conditions can be found, the assumed value of C_{D_0}, and the highest aspect ratio which is structurally reasonable. Given suitable structure weight data, a suitable span can then be chosen. Apart from the usual assumptions about weight of pilot, and so on, it would be wise to allow for about three times the amount of miscellaneous equipment considered by any previous designer. Oxygen, batteries, rotary converters and radio should not be accompanied by prickings of conscience about all-up weight.

It seems probable that the final answer would involve a span of about 65 ft., an aspect ratio of 20 or 22, a wing loading of about 4.5 lb. per sq. ft. and the use of flaps when circling in thermals. One would also like a higher rate of roll than is at present usual, more directional stability, a rudder which does not over-balance in a side-slip, 3 inches more elbow room and a maximum aero-towing speed of about 80 m.p.h. It must also be at least as easy as the "Weihe" to rig, and a good deal more accessible for adjustment of turnbuckles, and so forth. Some method of construction, such as that called for by H. Kendall in the design which won the B.G.A. two-seater design competition would help to keep the price practicable—for the benefactor by whom it would have to be financed!

*Sailplane Design, K. G. Wilkinson, A.F.R.Ae.S. Lecture to the Graduate and Student Section 28th September 1948. Summary published November 1948.

THE ICING OF SAILPLANES

By P. RIVERS, B.Sc.(Eng.), Grad.R.Ae.S.

While strenuous efforts are being made to protect all aircraft likely to fly in icing conditions, high flying sailplanes, which in summer are more likely to meet icing than any aircraft, are unable to carry any general protection whatsoever.

The lack of a power supply rules out all forms of wing protection, mechanical, fluid, or thermal, but so far no major aerodynamic trouble has been caused by ice-formation, as the low speed of the sailplane renders the actual catch of water small, and keeps the ice-formation down to a strip a few inches wide along the leading edge. The only danger in this direction lies in the possible jamming of the controls by ice forming on exposed control horns or on the tips of horn balances; the former can be shielded fairly easily, while horn balances are going out of favour on advanced machines.

The icing-up of air brakes is more serious since these are the sailplane pilot's standby if he reaches a dangerous high speed condition while flying blind; they must be kept free at all costs. They can be prevented from icing in the closed position by gentle exercising of them every minute or so, but they ice up rapidly when out, so that a pilot who uses them may find himself having to land with the brakes jammed open.

The main concern of pilots is to keep their blind flying instruments operating. For this reason electrically-driven turn and slip indicators are used in preference to venturi-driven ones. The air speed indicator is still vulnerable, however, as it must operate from a venturi or pitot tube, which will ice up. Pitot tubes rarely block during icing, as the ice forms a continuation of the tube, but during descent the ice thaws and runs back into the tube. Heated pitot-static heads for power aircraft consume 70-100 watts, so are impracticable for sailplanes; most of this heat is required to keep the complete head ice-free and thus obtain a true static pressure.

The cockpit static pressure is accurate enough for sailplane use, so the problem becomes one of protecting only the tip of the pitot tube. Recently a number of people have concentrated their attention on this point, and it seems possible that soon this bogey also will be laid.

RESIGNATION

The Committee of the Graduate and Student Section have regretfully accepted the resignation of one of their members, Mr. J. G. Roxburgh (Graduate), who is leaving the London area. Mr. Roxburgh has been a member of the Committee for a number of years, and has recently acted as Secretary to the Reading Branch of the Society.

The Graduate and Student Committee wish him all success in his new position.

THE ROYAL AERONAUTICAL SOCIETY
4 HAMILTON PLACE, PICCADILLY, LONDON, W.1. GROSVENOR 3515-9

NOTICES FEBRUARY 1950

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THE AERONAUTICAL QUARTERLY

Part IV of "The Aeronautical Quarterly" will be ready towards the end of February and may be obtained from the offices of the Society, 4 Hamilton Place, W.1, at 7s. 9d. each to members of the Society, post paid, or 10s. 3d. each to non-members, post paid.

Copies of Parts I, II and III are still available.

The contents of Part IV are:—

A Note on the Bending Moment Induced in the Booms of a Spar at the Point of Application of a Concentrated Load ... ... H. F. Winny
Strength of Aeroplanes in Relation to Repeated Loads D. Williams
The Supersonic Flow Past a Slender Ducted Body of Revolution with an Annular Intake ... ... G. N. Ward
The Steady Circulatory Flow about a Circular Cylinder with Uniformly Distributed Suction at the Surface ... J. H. Preston
Note on Control Reversal Effects on Swept-Back Wings W. H. Wittrick
Reviews Index to Volume I

The special attention of members is drawn to the fact that a strictly limited edition only of "The Aeronautical Quarterly" is printed and numbers cannot be reprinted in any circumstances.

GARDEN PARTY—1950

The Society's Annual Garden Party will be held on Sunday, 14th May 1950. Members will receive further particulars later.

NEW YEAR HONOURS

The following Members were included in the New Year's Honours List:—

K.B.E.

Air Vice-Marshal A. de T. Nevill (*Associate Fellow*. President New Zealand Division).

C.B.

S. Scott Hall (*Fellow*).
Air Commodore J. F. Titmas (*Associate Fellow*).

C.B.E.

F. M. Owner (*Fellow*).
K. T. Spencer (*Fellow*).

O.B.E.

R. M. Clarkson (*Fellow*)
W. Courtenay (*Associate*).
G. B. S. Errington (*Associate Fellow*).

M.B.E.

J. Norman (*Associate Fellow*).

KING'S COMMENDATION FOR VALUABLE SERVICES IN THE AIR

Air Vice-Marshal D. C. T. Bennett (*Fellow*).

INSTITUTE OF THE AERONAUTICAL SCIENCES

The Council of the Institute has announced the following elections:—

To *Fellowship*:

Dr. J. J. Green, F.R.Ae.S.

A. E. Russell, F.R.Ae.S.

Bo K. Lundberg, A.F.R.Ae.S.

GUGGENHEIM MEDAL

The Guggenheim Medal (U.S.A.) for 1950 has been awarded to Dr. E. P. Warner, *Honorary Fellow*. The medal is awarded for pioneering in research and a continuous record of contributions to the art and science of Aeronautics.

POST-GRADUATE AWARDS FOR TECHNOLOGY

The Ministry of Education has announced that some 50 more post-graduate awards for the Study of Technology are to be made available for 1950-51 at selected Universities and Technological Institutions in the United States.

The awards, tenable initially for a minimum of one year, are open to students with a good Honours Degree in Pure Science or Technology who have had at least two years' industrial experience and who are now working in industry, in research institutions, or who are teaching in Universities or Technical Colleges.

Full details may be obtained from the Ministry of Education (F. E. Division I), Curzon House, Curzon Street, London, W.I. Applications should be received by 15*th February* 1950.

WIND TUNNEL FACILITIES

Mr. T. P. Wright, who is now Vice-President for Research at Cornell University, has informed the Secretary that the 8½ ft. × 12 ft. variable density wind tunnel at the Cornell Aeronautical Laboratory is not being fully used and could be made available for model tests to aircraft companies in Great Britain which have not sufficient wind tunnel facilities. Attached to the wind tunnel is a fully-equipped Model Shop where precision wind tunnel models, including power units, can be made.

During the past two years the Cornell Wind Tunnel has done work for the U.S. Navy, Army and Air Force, for various United States firms, including the United Aircraft Corporation and Douglas Aircraft Company Inc., and for A. V. Roe Canada Ltd.

Anyone interested in the facilities offered should write to the Director, Dr. C. C. Furnas, the Cornell Aeronautical Laboratories, 4455 Genesee Street, Buffalo, Roe Canada Ltd.

MEMBERS' NEW APPOINTMENTS

H. G. Bloss, *Associate Fellow*—Director of Long Term Production Planning, Ministry of Supply.

E. T. Jones, *Fellow*—Principal Director of Scientific Research (Air), Ministry of Supply.

H. C. Pritchard, *Fellow*—Chief Superintendent, Long Range Weapons Establishment, Adelaide, Australia.

Air Commodore J. H. C. Wake, *Associate Fellow*—Bristol Aeroplane Company's representative for South Africa, Northern and Southern Rhodesia and Portuguese East Africa.

J. Woodhouse, *Associate*—Deputy Chief Engineer, West African Airways Corporation, Nigeria.

A. D. Young, *Associate Fellow*—To the Chair of Aerodynamics, College of Aeronautics, Cranfield.

LECTURES—SPRING 1950

MAIN LECTURES

(*At 6 p.m. at the Institution of Civil Engineers, Great George Street, S.W.1, unless otherwise stated. Tea will be served at 5.30 p.m.*)

Thursday, 2nd March 1950—Design for Maintenance, by R. E. Bishop, C.B.E., F.R.Ae.S.

Thursday, 16th March 1950—Air Survey, the Application of Modern Techniques to Surveying and Mapping, by Prof. C. A. Hart, M.Sc.(Eng.), Ph.D., M.Inst.C.E., F.R.I.C.S.

Thursday, 30th March 1950—Modern Methods of Testing Aero-Engines and Power Plants, A. C. Lovesey, O.B.E., B.Sc., F.R.Ae.S.

Thursday, 13th April 1950—The Berlin Air Lift, Air Commodore J. W. F. Merer, C.B.

Thursday, 27th April 1950—AT MANCHESTER—Recent Developments in High Speed Research in the Aerodynamics Division of the N.P.L., J. A. Beavan, M.A.(Cantab), A.F.R.Ae.S., and D. W. Holder, D.I.C., A.C.G.I., B.Sc.—**at the Chemistry Lecture Theatre, Manchester University, at 6.30 p.m.**

Thursday, 4th May 1950—3rd LOUIS BLERIOT LECTURE—IN PARIS, Sir Frederick Handley Page, C.B.E., F.I.Ae.S., Hon.F.R.Ae.S.

Thursday, 25th May 1950—38th WILBUR WRIGHT MEMORIAL LECTURE, Sir Richard Fairey, M.B.E., F.R.Ae.S.

SECTION LECTURES

(*At 7 p.m. in the Library, 4 Hamilton Place, London, W.1, unless otherwise stated.*)

Tuesday, 14th February 1950—Prototype Testing of Aircraft, D. R. H. Dickinson, A.F.R.Ae.S.

Tuesday, 21st February 1950—Air Intake Design for High Speed Aircraft, Dr. J. Seddon, B.Sc.

Tuesday, 21st March 1950—Boundary Layer at High Speeds, A. D. Young, M.A., A.F.R.Ae.S.

Tuesday, 25th April 1950—Flight Refuelling and the Problem of Range, C. H. Latimer Needham, M.Sc., F.R.Ae.S.

BRANCH LECTURES

BELFAST BRANCH

Tuesday, 21st February 1950—Strength Testing of Aircraft, Dr. P. B. Walker, M.A., Ph.D., F.R.Ae.S.

Tuesday, 14th March 1950—Problems of High Speed Flight, H. Davies, M.Sc., F.R.Ae.S.

Tuesday, 4th April 1950—Annual General Meeting.

In the Central Hall, College of Technology, Belfast, at 7 p.m.

BIRMINGHAM BRANCH

Friday, 24th February 1950—A Chat on Aero-Engines, Air Commodore F. R. Banks, C.B., F.R.Ae.S.

Friday, 31st March 1950—President's Night, Dr. S. C. Redshaw, F.R.Ae.S.

Friday, 21st April 1950—Annual General Meeting and Smoking Concert—*at the White Horse Hotel.*

Meetings are usually held at the Birmingham Chamber of Commerce at 7.15 p.m.

BRISTOL BRANCH

Monday, 13th February 1950—Aerial Photography, Group Captain F. C. V. Laws, C.B., C.B.E.

Monday, 27th February 1950—The Role of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

Monday, 13th March 1950—Junior Members' Papers Competition.

Monday, 27th March 1950—Gliding, A. H. Yates, Esq., B.Sc., A.F.R.Ae.S.

Wednesday, 5th April 1950—Recent Developments in Aircraft Production and Engineering, Professor J. V. Connolly, B.E., A.F.R.Ae.S.

Monday, 24th April 1950—Annual General Meeting and Film Show.

In the Conference Room, Bristol Aeroplane Co. Ltd., Filton House, at 6 p.m.

BROUGH BRANCH

Wednesday, 5th April 1950—Design Problems of the Flying Boat, H. Knowler, F.R.Ae.S., A.M.I.C.E.

In the Lecture Hall, Electricity Showrooms, Ferensway, Hull, at 7.30 p.m. Admission by ticket only, because of limited accommodation.

COVENTRY BRANCH

Wednesday, 15th February 1950—The Ghost Engine Installation of the Comet, W. T. Winter.

Wednesday, 15th March 1950—Flying Boats, H. Knowler, F.R.Ae.S., A.M.I.C.E.

Wednesday, 19th April 1950—Annual General Meeting and Films.

In the Trinity Hall, Ford Street (near Pool Meadow) at 7.30 p.m. Membership cards must be shown at all lectures.

GLASGOW BRANCH

Tuesday, 21st February 1950—Lecturettes.

Thursday, 23rd March 1950—Fuel Consumption, J. Leggatt, Student R.Ae.S.

At the St. Enoch Hotel, Glasgow, at 7.30 p.m.

GLOUCESTER AND CHELTENHAM BRANCH

Wednesday, 29th March 1950—*at Gloucester*—Materials of Aircraft Construction and Material Processing, Dr. H. Sutton, D.Sc., F.R.Ae.S., F.I.M.

Thursday, 20th April 1950—*at Cheltenham*—Annual General Meeting.

Gloucester Meetings (Wednesdays) are held in the Wheatstone Hall, City Library, Brunswick Road, at 7.30 p.m.

Cheltenham Meetings (Thursdays) are held in the Empire Hall, North Street, at 7.30 p.m.

ISLE OF WIGHT BRANCH

Thursday, 23rd February 1950—The Application of Propeller Turbines to Civil Air Liners, E. J. Richards, M.A., B.Sc., A.F.R.Ae.S.

Thursday, 9th March 1950—High Speed Research, J. D. Derry.

Thursday, 23rd March 1950—Gliding, P. A. Wills, C.B.E.

In the Saunders-Roe Sports and Social Club at 6 p.m.

MANCHESTER BRANCH

Wednesday, 22nd March 1950—Accident Investigation, Air Commodore Vernon S. Brown, C.B., O.B.E., M.A., F.R.Ae.S.

In the Reynolds Hall, College of Technology, unless otherwise stated.

PORTSMOUTH BRANCH

Friday, 10th March 1950—Design Problems of Large Flying Boats, H. Knowler, F.R.Ae.S., A.M.I.C.E.

Friday, 7th April 1950—The Probable Role and Influence of Aircraft in Future Warfare, Air Marshal Sir Robert Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C.

In the Lecture Room, Central Library, at 7 p.m.

PRESTON BRANCH

Wednesday, 22nd February 1950—Radar and the Aircraft which use it, B. W. Hodlin, B.Sc.

Wednesday, 15th March 1950—Lecturettes. Branch Members.

Wednesday, 26th April 1950—Annual General Meeting.

At the Assembly Hall of the Technical College, Corporation Street, at 7.30 p.m.

READING AND DISTRICT BRANCH

Wednesday, 22nd February 1950—An Informal Address on Propeller-Turbines, A. C. Clinton, F.R.Ae.S.

Wednesday, 12th April 1950—Flying Boats, H. Knowler, F.R.Ae.S.

At the Abbey Gateway Rooms at 7.30 p.m.

WEYBRIDGE BRANCH

Wednesday, 1st March 1950—Do Scientists Know Anything? C. G. Grey, *Founder Member* R.Ae.S.

Wednesday, 22nd March 1950—Junior Prize Lecture, Branch Members.

Wednesday, 31st May 1950—Annual General Meeting.

At Vickers-Armstrongs Ltd., Weybridge Works, at 6 p.m., unless previous notice is given.

GRADUATES' AND STUDENT SECTION

Thursday, 23rd February 1950—Some Problems of Heat Transfer, W. R. Shapey, B.Sc., Grad.R.Ae.S., and J. Rivers, Grad.R.Ae.S.

Wednesday, 1st March 1950—A Joint Meeting with the Graduate Sections of the Institution of Electrical Engineers and the Institution of Mechanical Engineers. Some Engineering Problems of Aircraft Design.

*This meeting will be held at 7 p.m. at the Institution of Mechanical Engineers, Storeys Gate, S.W.*1.

Tuesday, 7th March 1950—Gas Turbine Installation, J. C. Wallin, B.Sc., A.F.R.Ae.S.

Tuesday, 28th March 1950—Undercarriage Design and Testing, G. S. Cranwell, Grad.R.Ae.S.

Tuesday, 18th April 1950—A Discussion Evening on The Training of Aeronautical Engineers. Chairman: Marcus Langley, F.R.Ae.S. *All members of the Society are particularly invited to take part in this discussion.*

Meetings are held in the Library, 4 Hamilton Place, W.1, at 7.30 p.m., unless otherwise stated.

JOURNAL BINDING

The new prices of binding of Journals is as follows:—

1949 Volume (including packing and postage), 15s. 6d.

Previous Volumes (including packing and postage), 17s. 0d.

Journals should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Cases only for unbound 1949 Volumes are available, price 6s. 6d. each. Requests for cases, with remittances, should be sent to the Secretary at the offices of the Society.

ANNUAL SUBSCRIPTIONS

Members are reminded that their annual subscriptions became due on 1st January 1950. The rates are:—

	Home	Abroad
	£ s. d.	£ s. d.
Fellows	5 5 0	4 4 0
Associate Fellows	4 4 0	3 3 0
*Associates	3 3 0	3 3 0
Graduates (aged under 26)	2 2 0	2 2 0
Graduates (aged 26 and over)	2 12 6	2 12 6
Students (aged under 21)	1 1 0	1 1 0
Students (aged 21 and over)	1 11 6	1 11 6
Companions	3 3 0	3 3 0
Founder Members	2 2 0	2 2 0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership.

Remittances should be made payable to the Royal Aeronautical Society.

CHANGE OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

ELECTIONS

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Ernest Henry Alford, Robert Allan, Ian Kenneth Bennett (from Student), Arthur Harry Oliver Brown, Frank Frederick John Butler, Denison Campbell-Allen, Leslie Ellerd-Styles, Necdet Eraslan, Jeffrey Hammerton Harwood (from Student), Dennis Hill, Leon Massie, William Henry Mayall (from Graduate), Raymond Frederick Sargent (from Associate), Gordon Morrison Silvester (from Graduate), Harold James Staite, John Wallace Titterton.

Associates

Douglas Raymond Bevis, Gordon Davies, Derek Eccles, Thomas Hewitt, Charles Henry Johns, Archibald Cranleigh Stagg.

Graduates

Norbert Abeles, Peter Joseph Angus, Kenneth Bickerstaff, Michael Booth (from Student), James Robert Campbell, (1) Peter Walker Campbell, (2) Peter Walker Campbell, Roy Edward Champken, John Maurice Chard, Eric Alan Coates (from Student), Alan Frederick Boniface Constantine (from Student), Peter Herbert Cook (from Student), Anthony David Cowell (from Student), Peter John Cunningham, Alan Robert Daffey, Jack Sidney Dean (from Student), Clifford Ditchfield, Arthur David Ellis, Stanley Hargreaves Ellis (from Student), William Little Farish, Robert Charles Godwin (from Student), Alan James Greenhalgh, Stuart William Greenwood (from Student), John Harold Grout, Peter John Hext Hall, John Dennis Hallett, Vernon Alexander Hallett, John Hawthornthwaite, Donald William Hayward, James Rentoul Henry (from Student), Rodney Graham Hinkley (from Student), John Ernest Hommert (from Student), Michael Stanley Stather Hunt, Derek Anthony Jackson, Arthur Albert Jacobs (from Student), John Einion Glyn Jones, Derrick Pritchard Jones, George Charles Brian Harvey Kenrick (from Student), John Nevil Kirkby, David Leek, Philip Reginald Lewis, Romney Hollins Lowry, Ian Stuart Mant, Alexander Leslie Mayne, Francis John Morley, Roger Hetherington Peart, Bertram Anthony Peaster, James Stanford Plowman (from Student), Brian Ben Priestley, David Ronald Arthur Puttock, John Patrick Charles Richards, Terence Compton Stamp, Xavier Hubert Joseph Strick, Peter Anthony Tanner, Peter George Taylor, Peter Drake Thompson, Stephen William Tonkin (from Student), Robert Longley Trillo (from Student), Alexander Uydens (from Student), Peter Redmore Ward, Peter Ernest Watts (from Student), Rex Wheatley, Peter Charles Harford White (from Student), George Wilson, Mieczyslaw Longin Wisniewski, Wilfred Joseph Woods (from Companion).

Students

Ronald Edward Bellew, Dennis Ryan Brodie, William Tudor Gunston, Lars Eric Haggstrom, Thomas Henry Jones, Lois Jennifer Lee, Basil Thomas Lewis, Victor Stephen Lodge, Philip Arthur Norman, Rees Oakes, David William Rowe, Edmundo Gomes Ferreira daSilva, Gordon Sim, Paul Simpson, Anthony Compton Southgate, Christopher Staffurth, Michael Jordan Taylor.

Companions

Saul Jecies, Norman Leslie Edwin King (from Student), Ved Kumar, Eldon Malcolm Phillips, Kulbir Singh (from Student).

ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks a souvenir air cover carried in the "Truculent Turtle" on its record-breaking flight from Perth, Australia, to Columbus, Ohio (11,236 miles), from Lt. Cdr. R. F. Freitag, U.S.N., *Associate Fellow*.

The Council also acknowledge with thanks the return of back numbers of the JOURNAL from P. S. Lamb, Esq., and back numbers of the JOURNAL and other publications from Geoffrey Smith, Esq., Editorial Director of *Flight*.

ADDITIONS TO THE LIBRARY

Pamphlets in italics. Books marked * or ** may not be taken out on loan.

A.a.373—Vibration and Flutter Prevention Handbook. U.S.A.N.C. Committee. U.S. G.P.O. 1948.

*A.a.374—The Science of Flight. O. G. Sutton. Penguin. 1949.

A.b.89—Dynamics of Real Fluids. E. G. Richardson. Edward Arnold. 1950.

B.b.32—Vertical Flight. P. C. Grose. General Publishing Co. 1947.

B.f.108—From Birds to Aeroplanes. T. L. Bartlett. Royal Society for the Protection of Birds.

D.c.122—Airport Design. Civil Aeronautics Administration. 1949.

E.b.144—Structural Analysis by Moment Distribution. S. Butterworth. Longmans Green. 1949.

E.d.40—Three-Dimensional Engineering Drawing. W. E. Walters. Pen-in-Hand Books. 1949.

E.f.118—Aircraft Maintenance and Repair. Northrop Aeronautical Institute. McGraw Hill. 1949.

E.g.14—Oil Hydraulic Power and its Industrial Applications. W. Ernst. McGraw Hill. 1949.

F.b.48—Standard Methods for Testing Petroleum and its Products. 10th Edition. Institute of Petroleum. 1949.

G.a.91—Industrial Metallurgy. L. Aitchison. Macdonald and Ewans. 1949.

G.e.G.27—Design of Wood Aircraft Structures. A.N.C. Committee. U.S. G.P.O. 1944.

M.b.58—Recent Advances in Radio Receivers. L. A. Moxon. Cambridge University Press. 1949.

M.c.87—Radar Beacons. A. Roberts. (Editor). McGraw Hill. 1947.

S.e.18—History of United States Naval Aviation. A. D. Turnbull and C. L. Lord. Yale University Press. 1949.

*X.c.M.27—Lexicon of Aeronautical Terms. I.C.A.O. 1949.

N.A.C.A. Technical Notes

1219—*Stress analysis by recurrence formula of reinforced circular cylinders under lateral loads. J. E. Duberg and J. Kempner.*

1926—*The application of the statistical theory of extreme values to gust-load problems. H. Press.*

1945—*Aerodynamic characteristics of 15 NACA airfoil sections at seven Reynolds numbers from* 0.7×10^6 *to* 9.0×10^6. *L. K. Loftin, Jnr., and H. A. Smith.*

1955—*Preliminary investigation at supersonic speeds of triangular and sweptback wings. M. C. Ellis, Jnr., and L. E. Hasel.*

1958—*Analysis of ejector thrust by integration of calculated surface pressures. J. C. Sanders and V. L. Brightwell.*

1959—*Gust-tunnel investigation of a flexible-wing model with semichord line swept back 45 degrees. R. D. Reisert.*

1961—*Investigations relating to the extension of laminar flow by means of boundary layer suction through slots. L. K. Loftin, Jnr., and D. L. Burrows.*

1962—*Stresses in and general instability of monocoque cylinders with cutouts. VII—Experimental investigation of cylinders having either long bottom cutouts or series of side cutouts. N. J. Hoff, B. A. Boley and J. J. Mele.*

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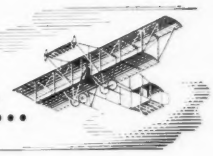

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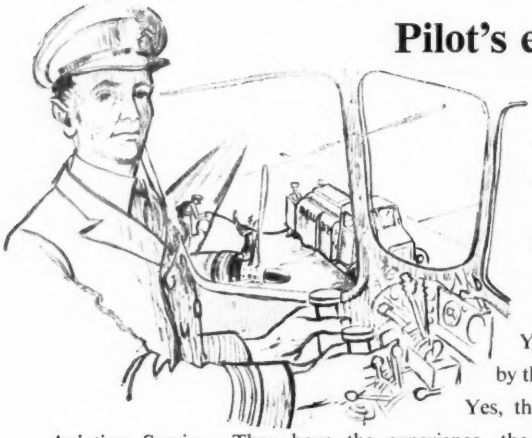

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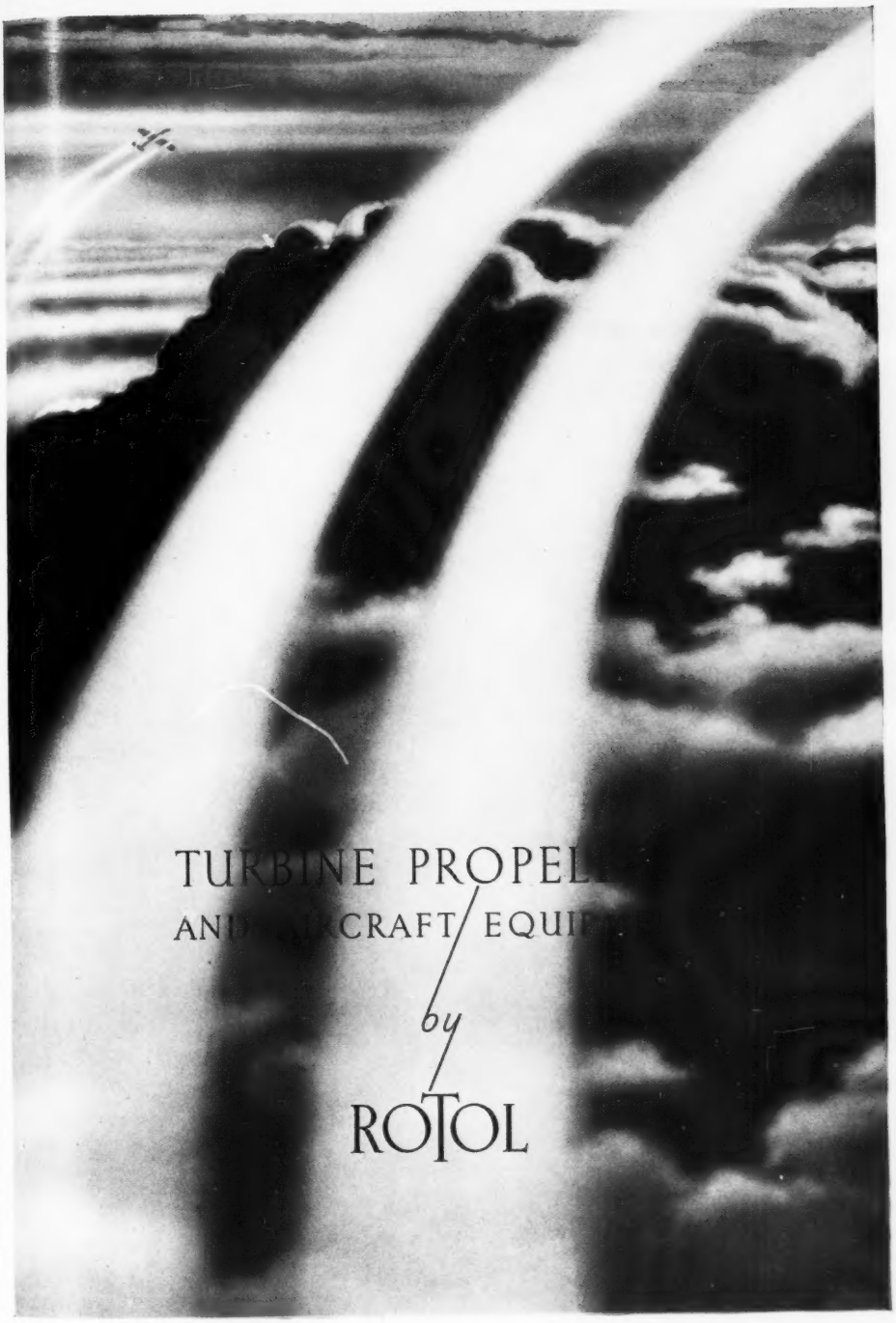
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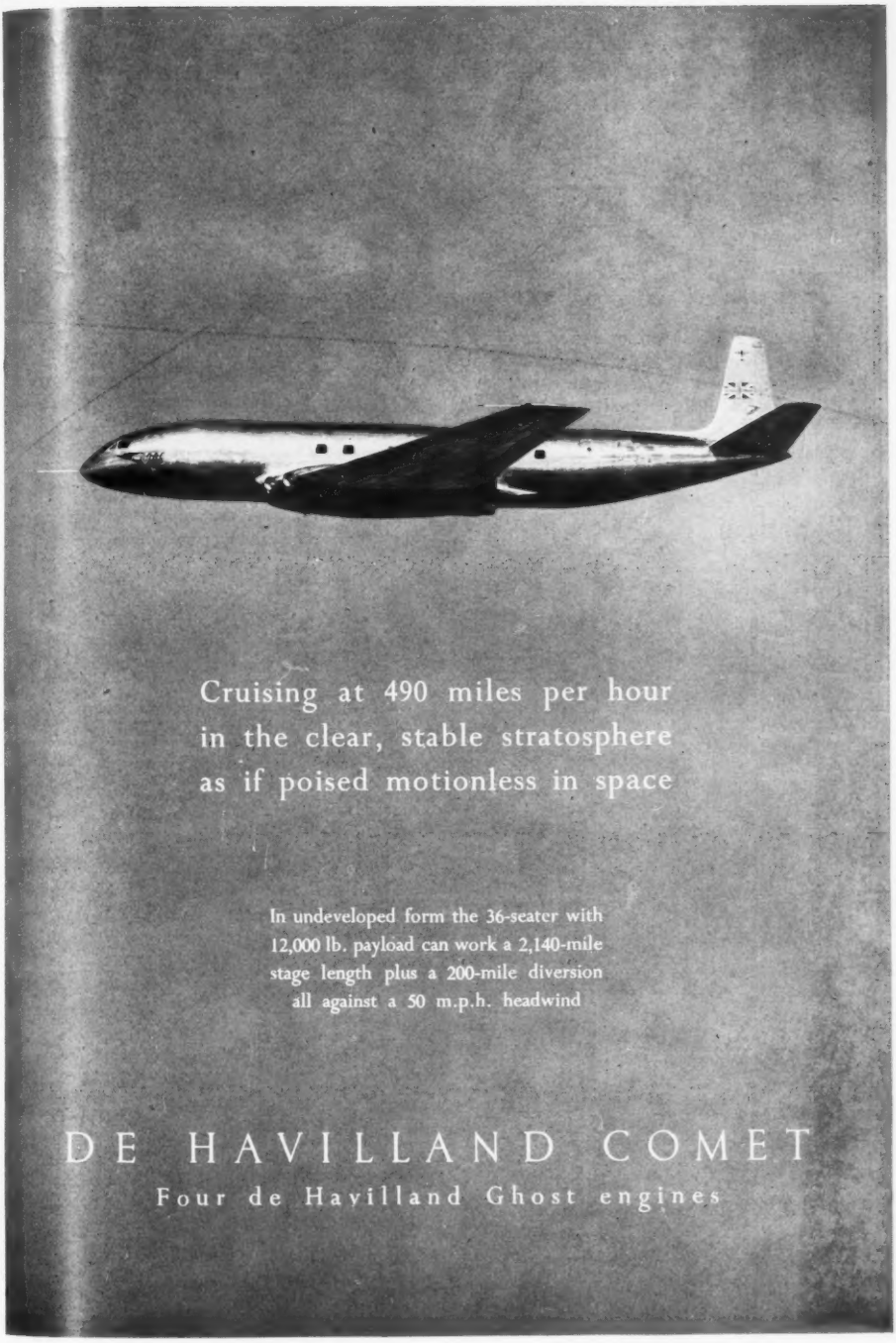
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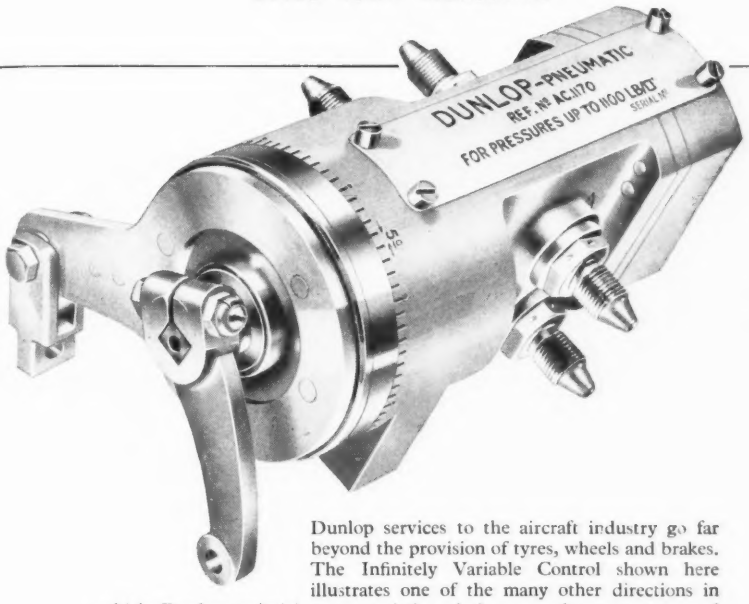

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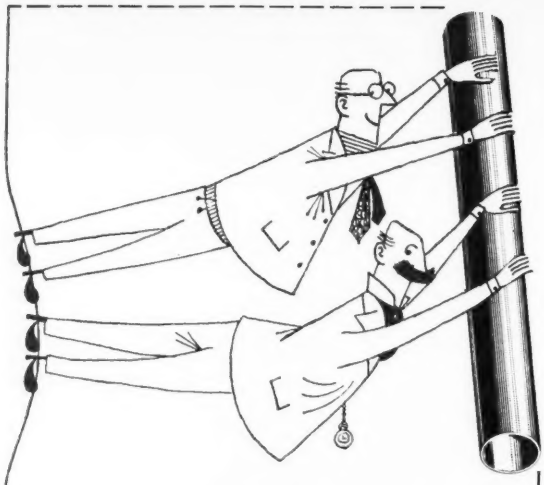

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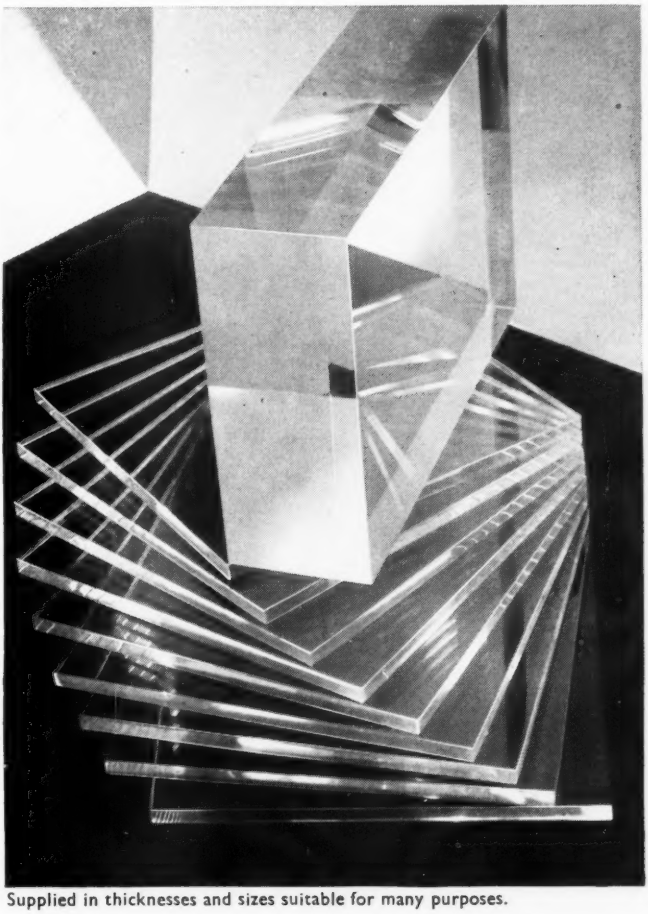

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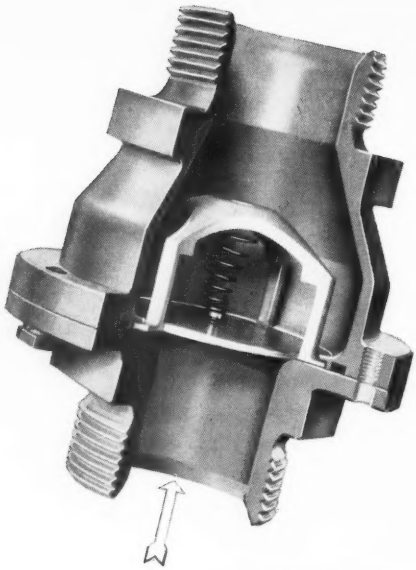

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AIRCRAFT DESIGN ANALYSIS

by

IVAN H. DRIGGS, A.E., F.I.Ae.S., F.R.Ae.S.

The 781st Lecture to be read before the Royal Aeronautical Society was delivered on 6th October 1949 at the Institution of Civil Engineers, Great George Street, London, S.W.1. The President of the Society, Sir John S. Buchanan, C.B.E., F.R.Ae.S., introduced the Lecturer, Mr. Ivan H. Driggs, A.E., F.I.Ae.S., F.R.Ae.S., Director of the Research Division of The Bureau of Aeronautics Department of the United States Navy.

1. INTRODUCTION

I have chosen to describe the methods employed by the Research Division of the United States Navy Bureau of Aeronautics with the hope that others engaged in a similar line of endeavour may be able to make profitable use of this information in the solution of their specific problems. The development of the material to be discussed arose directly from the need for quick, reasonably accurate and simple means for studying a broad series of aircraft designs leading toward fulfilling an overall military requirement. This process is carried out in the Bureau of Aeronautics by the Research Division prior to the issuing of a type specification with a request for proposal to the various manufacturers. Before these specifications are decided upon, many designs must be investigated and reported to those initially responsible for the issuing of military requirements. By this process intelligent compromises are arrived at and the best possible aeroplane chosen. These compromises reflect the performance, the ability of operation from carriers, and the effectiveness of the design as a military weapon.

The Research Division has a staff of approximately eight engineers working on this specific problem for both piloted and pilotless aircraft, so that it is apparent that if the required service is to be rendered, special methods must be developed and utilised to the greatest extent. Many times, it has been necessary to render a complete report on a new project in two or three weeks. We cannot have a large staff of calculators or special calculating machines to do this work so we must rely upon the designers themselves to produce the information and so devise and organise the methods used that a minimum of their time will be spent in routine calculations. The procedures described arise directly from this necessity and from a strong desire to rationalise and to express all the factors which pertain to the art of aircraft design in their proper relationships. This leads directly to better understanding of any given problem and therefore assists the designers in arriving at intelligent courses of action.

I will discuss the following main subjects: Performance Estimation of the Aeroplane, Turbine Engine Performance, the Performance of the Propulsive System and the Estimate of Weight. Much has been written upon each of these subjects but, I believe, none of the methods employed by the Research Division has been described elsewhere, at least not in a complete paper which ties together all of the above subjects into one complete whole. The approach to each of these specific problems is designed to be used in a rational, integrated solution. That is, each subject has been developed with reference to its effect upon the others, rather than a piecemeal, uncorrelated series of schemes for the solution of these various problems borrowed from existing textbooks or remembered from our university or college days. Most of the methods described, therefore, may be considered original with the Research Division. They are not the result of the thinking of any one man, but rather the result of team-work and the accumulated thinking and experience of our whole group, inventing new methods and new ideas as new problems were met and solved.

2. NOTATION

A = Constant
B = Constant
B = Width of Hull or fuselage—ft.
b = Span of wing—ft.
C = Chord of wing—ft.
C = Carbon
C = Coefficient
CR = Critical
C_p = Specific heat at constant pressure
D = Drag
e = Span efficiency factor
e = Base of natural logarithm
°F = Degrees Fahrenheit
f = Parasite area in sq. ft.
f = Average design unit stress in wing lb./sq. in.
G.H.P. = Generator horsepower
H = Hydrogen
H = Height of hull or fuselage in ft.
h = Enthalpy—B.Th.U./lb.
J = Mechanical equivalent of heat—778.26 ft.-lb./B.Th.U.
Jet H.P. = Net power for expansion in jet
K = A factor
L = Length of hull or fuselage in feet
M = Mach number
N = R.P.M.
n = Polytropic exponent
n.mi. = Nautical miles
n = Ultimate load factor
P = A parameter
p = Pressure—lb./sq. ft.
q = Dynamic pressure—lb./sq. ft.
°R = Degrees Rankine
R = Gas constant, 53.3 ft./°F.
S = Wing area—sq. ft.
S = Entropy—B.Th.U./lb. °F.
S.H.P. = Net shaft horsepower
s.f.c. = Specific fuel consumption
T = Temperature—°R
T.H.P. = Thrust horsepower
t = Thickness of wing—ft.
u = Velocity—ft./sec.
V = Velocity—knots
W = Weight—lb.
x, y = Factors in combustion efficiency equation
α = Exponent in empirical combustion efficiency equation
α = Factor in wing weight formula
β = Ratio between power used in driving shaft of a turbo-prop to total generator power under static conditions
β = Factor in wing weight formula
γ = Ratio of specific heats
Δ = Increment
δ = Ambient pressure at any altitude relative to sea level—standard conditions
ζ = Exponent in combustion efficiency empirical equation
η = Efficiency
θ = Ambient temperature at any altitude relative to sea level—standard conditions
Λ = Sweepback —°. at $\frac{1}{4}$ chord
σ = Ambient density at any altitude relative to sea level—standard conditions
τ = Ratio of total energy in moving air stream to the ambient or static energy

SUBSCRIPTS

$_a$ = Actual
$_a$ = Air
$_b$ = Burner
$_c$ = Compressor
$_D$ = Drag
$_D$ = Duct
$_f$ = Fuel
$_g$ = Generator
$_g$ = Gas
$_g$ = Gear
$_h$ = Hypothetical
$_i$ = Ideal
$_j$ = Jet
$_l$ = Lost
$_L$ = Lift
$_n$ = Nozzle
$_p$ = Power
$_p$ = Polytropic
$_p$ = Propeller or propulsive
$_r$ = Required
$_r$ = Root of wing
$_s$ = Shaft
$_s$ = Static
$_T$ = Total
$_t$ = Turbine
$_t$ = Tip of wing
$_v$ = Velocity

NUMERICAL SUBSCRIPTS

1. 2, 3, 4, 5, 5a, 6 = Stations shown in Fig. 9.

3. AIRCRAFT PERFORMANCE ANALYSIS

We have developed what might be called in mathematical terms a double infinite slide-rule for use in estimating aircraft performance. The embryonic idea of this

device was initially reported in Reference 1, but has been extended and materially improved in the course of the past few years. Equation (1) expresses the basic assumption upon which this system is based; that is, that the drag coefficient plotted against lift coefficient, with the effects of compressibility ignored, approximates a parabola, and when this drag coefficient is plotted against the square of the lift coefficient, substantially a straight line will result with an intercept at zero lift equal to the minimum profile drag coefficient and a slope equal to

$$S/(\pi\, b^2\, e^2) \quad . \quad . \quad (1)$$

$C_D = A + B\, C_L^2$
$A = C_{do}$, drag coefficient at zero lift $= f/s$
$B = S/(\pi\, b^2)$, theoretically
$B = S/(\pi\, b^2\, e^2)$, practically
b = Span—feet
S = Total wing area—sq. ft.
e = Span efficiency factor
f = Parasite area—sq. ft.—basic

For simplicity we fix upon one gross weight and one parasite area W_0 and f_0, the initial values. Corrections for changes in weight and parasite area for any given aeroplane design will be discussed later. Under these conditions Equation (2) follows directly by inserting the definitions of the various coefficients into Equation (1) and converting to horsepower units.

$$\frac{\text{T.H.P.}_r}{\delta\sqrt{\theta}} = 0.00001041\left(\frac{V}{\sqrt{\theta}}\right)^3 f_0 + \frac{0.2885}{V/\sqrt{\theta}}\left(\frac{W_0}{\delta\, b\, e}\right)^2 . \quad (2)$$

If this equation is minimised, the velocity at which minimum thrust horsepower required occurs is given by Equation (3) and if Equation (2) be transformed to a drag equation, minimisation of the resulting formula will give the velocity for minimum drag or maximum lift/drag ratio as shown in Equation (4).

$$\frac{V}{\sqrt{\theta}} \text{at Min. T.H.P.}_r = 9.80\left(\frac{W_0}{\delta\, b\, e}\right)^{\frac{1}{2}} \Big/ f_0^{\frac{1}{4}}, \text{ knots} \quad . \quad . \quad . \quad . \quad (3)$$

$$\frac{V}{\sqrt{\theta}} \text{at Min. Drag} = 12.90\left(\frac{W_0}{\delta\, b\, e}\right)^{\frac{1}{2}} \Big/ f_0^{\frac{1}{4}}, \text{ knots} \quad . \quad . \quad . \quad . \quad (4)$$

These equations contain the same algebraic functions of the weight, effective span, parasite area and relative pressure and, therefore, suggest a transformation of co-ordinates of the thrust horsepower required curve by substituting Equations (5) and (5*a*) for the velocity.

$$\left.\begin{aligned} \frac{V}{\sqrt{\theta}} &= K_v \frac{P_v}{\delta^{\frac{1}{2}}} \\ K_v &= \text{a Factor} \end{aligned}\right\} \quad . \quad . \quad (5)$$

$$\left.\begin{aligned} P_v &= \text{Speed Parameter} \\ &= \left(\frac{W_0}{b\, e}\right)^{\frac{1}{2}} \Big/ f_0^{\frac{1}{4}} \end{aligned}\right\} \quad . \quad (5a)$$

Inserting these expressions into Equation (2) leads to Equation (6).

$$\frac{\text{T.H.P.}_r/(\delta\sqrt{\theta})}{[W_0/(\delta\, be)]^{\frac{3}{2}} f_0^{\frac{1}{4}}} = 0.00001041\ K_v^3 - \frac{0.2885}{K_v} \quad (6)$$

Then this transformation indicates that the thrust horsepower required be considered as defined in Equation (7) and (7*a*).

$$\frac{\text{T.H.P.}_r}{\delta\sqrt{\theta}} = K_p \frac{P_p}{\delta^{\frac{3}{2}}} \quad . \quad . \quad (7)$$

$$P_p = \left(\frac{W_0}{b\, e}\right)^{\frac{3}{2}} f_0^{\frac{1}{4}} \quad . \quad . \quad (7a)$$

P_p = Power Parameter

Substituting into Equation (6) leads to:

$$K_p = 0.00001041\ K_v^3 + 0.2885/K_v \quad (8)$$

This equation is a completely general expression for the power required to fly any aeroplane, under parabolic assumption.

Writing Equations (5) and (7) logarithmically gives (9) and (10).

$$\log(V/\sqrt{\theta}) = \log K_v - \tfrac{1}{2}\log\delta + \log P_v \quad (9)$$

$$\log\frac{\text{T.H.P.}_r}{\delta\sqrt{\theta}} = \log\ K_p - \frac{3}{2}\log\delta + \log P_p \quad (10)$$

It is evident from these expressions that if Equation (8) be plotted upon double logarithmic paper, as shown in Fig. 1, the multiplication of both the ordinate and abscissa by the respective power and speed parameters may be accomplished by a simple shift of the origin, which makes this curve represent any desired aeroplane as defined by the two parameters P_v and P_p. It is also evident that these two parameters depend upon the same aircraft dimensions, the weight, the effective span and the parasite area but in different combinations.

Further expansion of (9) and (10) gives

$$\log(V/\sqrt{\theta}) = \log K_v - \tfrac{1}{2}\log\delta + \tfrac{1}{2}\log[W_0/(be)] - \tfrac{1}{4}\log f_0 \quad (11)$$

$$\log\frac{\text{T.H.P.}_r}{\delta\sqrt{\theta}} = \log K_p - \frac{3}{2}\log\delta + \frac{3}{2}\log\left(\frac{W_0}{b\, e}\right) + \frac{1}{4}\log f_0 \quad (12)$$

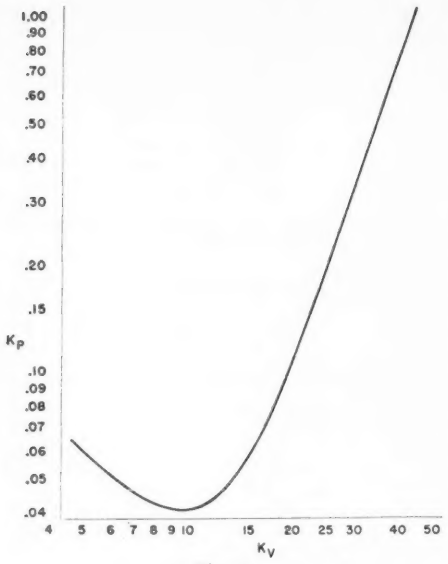


Fig. 1.

Generalised power required.

$$K_p = 0.00001041 K_v^3 + \frac{0.2885}{K_v}$$

These two equations differ only in the first terms, which are plotted in Fig. 1, and in the coefficients and signs of the other terms which depend upon the aircraft dimensions or flight altitude. It is evident that corrections for altitude, weight or span changes from any chosen initial set of conditions must be made along lines drawn on the logarithmic graph with slopes of 3:1, since the coefficients of those terms of Equations (11) and (12) are in that ratio. Similarly, changes in parasite area are made along lines of slope of minus one.

Figure 2 shows the transparent overlay which has resulted from the development of the rather simple ideas presented in the preceding discussion. This overlay is made up of three pieces, a Control Plate, a Guide plate and a Power-required Plate, as seen in this figure where the various parts have been separated. An origin or Control Point is indicated upon the Control Plate by the intersection of the horizontal and vertical lines. The co-ordinates of this Control Point have the values $K_p = 0.1$ and $K_v = 40$. The slope of the left-hand side of this plate is chosen to represent the relationship between the δ terms of Equations (11) and (12), that is, three to one, and upon this edge of the Control Plate a scale is indicated representing various altitudes from one to 70,000 ft. This is a scale of relative pressure and is used when computing the performance at a series of altitudes.

The L-shaped Guide Plate similarly has two scales—one along the right-hand edge graduated in per cent. of gross weight between 40 per cent. and 100 per cent. This scale is used for range calculation or for any condition where it is desired to obtain the performance at any other than full gross load. The other scale along the inner left-hand edge of the Guide Plate is graduated in a manner consistent with Equations (11) and (12) to account for increase in parasite drag that may be caused by exposure of turrets, flaps or other similar devices. This scale is also used when compressibility effects are encountered and accounts for the increase in drag with Mach number. Similarly, corrections for variations in drag from the parabolic assumption may be accomplished by this means.

The third plate, the Thrust-horsepower Required Plate contains the curve of Equation (8). This plate is so cut that the generalised power-required curve may be pencilled through on to the power-available chart, to be described later. A series of curves are drawn on this plate labelled ΔK_p. These curves are used in obtaining rate of climb. Since the rate of climb is determined by the excess of horsepower available over that required, it is not possible to determine this quantity in the usual manner on logarithmic co-ordinates. The distance between a power-available and power-required curve on these co-ordinates is the logarithm of the ratio between the two values rather than their difference. If contours of values of K_p in excess of the values required for level flight are constructed, then these quantities are proportional to the excess horsepower; hence the rate of climb may be obtained by their multiplication by the proper parameters. The curves on this Thust-horsepower Required Plate are such contours and the ratio between the rate of climb, the power parameter per unit weight and the square root of the relative density is designated as ΔK_p. Thus, the rate of climb may be obtained from Equation (13).

$$\text{Rate of climb} = \frac{33{,}000\, P_p\, \Delta K_p / \sigma^{\frac{1}{2}}}{W_0} \quad (13)$$

at initial conditions.

If the rate of climb is to be found in any other than the full gross weight or if drag or compressibility effects are present, Equation (14) must be used.

Rate of climb =

$$\frac{33{,}000\ P_p\ \Delta K_p}{W\sigma^{\frac{1}{2}}}\left(\frac{W}{W_0}\right)^{\frac{3}{2}}\left(\frac{f}{f_0}\right)^{\frac{1}{2}} \qquad (14)$$

The power available from any given propeller turbine engine will appear substantially as shown in Fig. 3. It will be noted that T.H.P./($\delta\sqrt{\theta}$) is plotted against $V/\sqrt{\theta}$ for both normal and military power at a series of altitudes up to the tropopause. A different character of line is used to distinguish between normal and military power. Likewise curves of constant $\delta \times$ n. mi./lb. are plotted across the power-available curves. These data can only be obtained after a propeller design has been chosen, but the Research Division has found that for practical reasons, two or possibly three, at the most, different propeller designs will be used on one turbo-prop engine and consequently no more than three of these power-available graphs are required. For a turbo-jet engine, on the other hand, only one is required since one type of propulsive unit, the nozzle, will be employed on these engines. These points will be discussed in a later section.

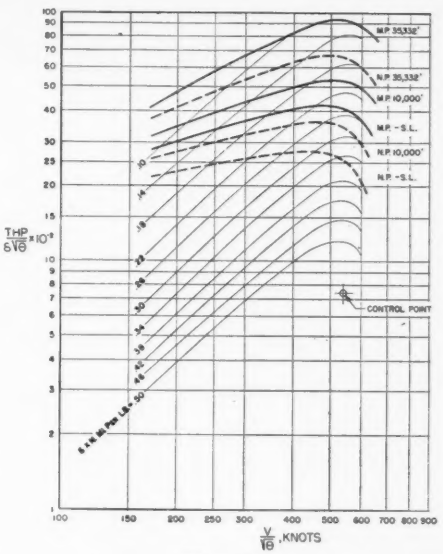


Figure 3.
Thrust horsepower, turbo-propeller.

To use this method of obtaining performance we proceed as follows:

1. From the known or estimated dimensions of the aeroplane, compute the speed and power parameters from Equations (5*a*) and (7*a*).

2. Compute the co-ordinates at which the Control Point of the Control Plate is to be located from Equations (15) and (16). Locate this point on the power-available graph as shown on Fig. 3.

$$\text{Control Point co-ordinates} \begin{cases} V/\sqrt{\theta} = 40\ P_v & (15) \\ \text{T.H.P.}/\delta\sqrt{\theta} = 0.1\ P_p & (16) \end{cases}$$

3. Place the Control Plate over the power-available chart with the Control Point of the overlay coinciding with the point just calculated above. Line up the horizontal and vertical lines parallel to corresponding lines of the power-available chart and weight down this Control Plate so that it cannot shift. (This plate is not moved during the performance analysis of the aeroplane whose dimensions have been chosen in computing the two parameters.)

4. Place the Guide Plate along the sloping edge of the Control Plate with the weight and altitude scales coincident. Set the unit weight ratio index of the Guide Plate opposite sea level and weight down.

5. Place the Power-required Plate in the corner of the *L* of the Guide Plate, fitting it tightly and pencil through to obtain a trace of the power required on the power-available chart for the sea level condition with no compressibility. (Fig. 4 shows the overlays placed above the power-available chart as described above. Except when a permanent graphic record is desired, the intersections between the curves can be read directly without drawing lines through on to the power-available chart.)

6. Read the intersections between the thrust horsepower-required curves for both normal and military power at sea-level and note the values of $V/\sqrt{\theta}$. Read the maximum value of ΔK_p which is tangent to the power-available curves, making any necessary interpolations. Likewise read the maximum value of $\delta \times$ n.mi./lb. which is tangent to the power-required curve, noting these values.

7. Shift the Guide Plate index upwards along the altitude scale of the Control Plate to any series of altitudes and repeat the process described in 6 above.

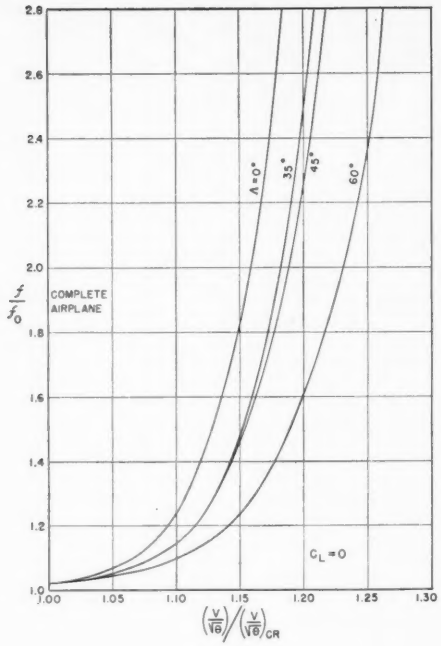


Fig. 5.
Drag rise.

8. For range calculation at the same series of altitudes shift the Guide Plate index downward for a few values of the ratio W/W_0 and read best $\delta \times$ n.mi./lb. for these weight ratios.

9. Multiply out the pressure and temperature ratios and determine the rate of climb from equations (13) or (14), and plot in the usual manner.

In case the parasite area is increased during the flight for any reason whatever, such as unretracted turrets, the icing shoes operating, or compressibility effects at high Mach number, the inner left-hand scale of the Guide Plate may be employed to correct for these effects, after the ratio f/f_0 has been estimated. In correcting for compressibility, the Research Division uses the drag rise curve in Fig. 5 but any other relationship may be used. From a knowledge of the sweepback and general aerofoil characteristics, an estimate is made of the value of $V/\sqrt{\theta}$ at which the drag starts to rise, then for all speeds above this value the ratio f/f_0 is determined from this graph and the power-required overlay is shifted upward and to the left along the inner scale of the Guide Plate, pencilling-in the power-required curve as it crosses the chosen speeds. After removal of the Power-required Plate, the whole curve can then be drawn through these points blending in to the unaffected portion of the power required. Such a curve is shown in Fig. 6.

So far, the two vertical scales on the Control Plate have not been discussed. These scales are ratios of K_p/K_{p0} and are used for a variety of purposes concerned with changes in thrust horsepower. It often happens that a new engine design is proposed, but the actual size and power will be decided upon after study in a series of aircraft designs. After the Control Point has been located, the Control Plate may be shifted upward (to decrease the engine power) or downward (to increase) and the effects of a wide series of possible similar engines studied. The right-hand scale, graduated up to 10, also represents an increase in total number of engines so that but one thrust horsepower-available graph is required when working with a multiple-engined aircraft. The left-hand scale graduated in decimals less than unity may be used to decrease the power for changes in propulsive efficiency or for inlet duct losses anticipated in a given design. The thrust

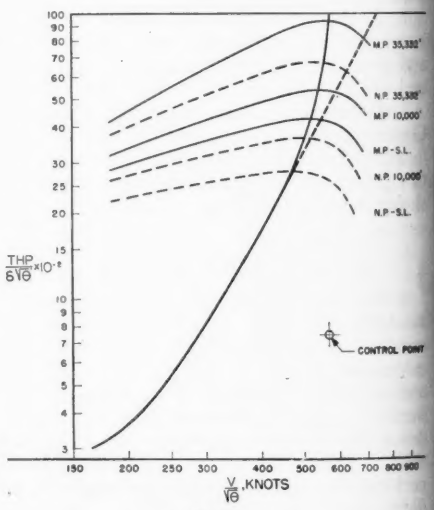
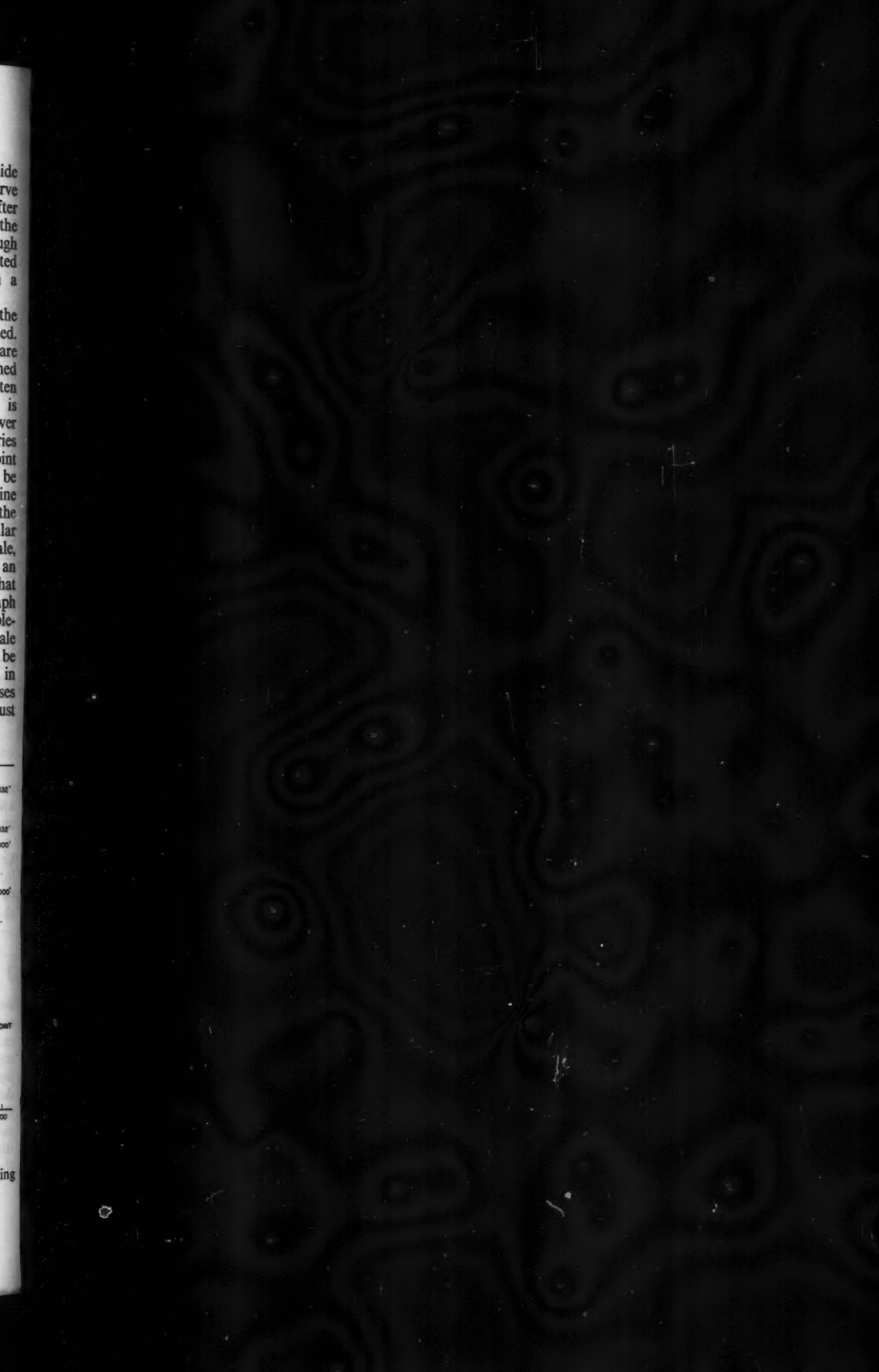


Fig. 6.
Power-available and power-required, illustrating compressibility effects.



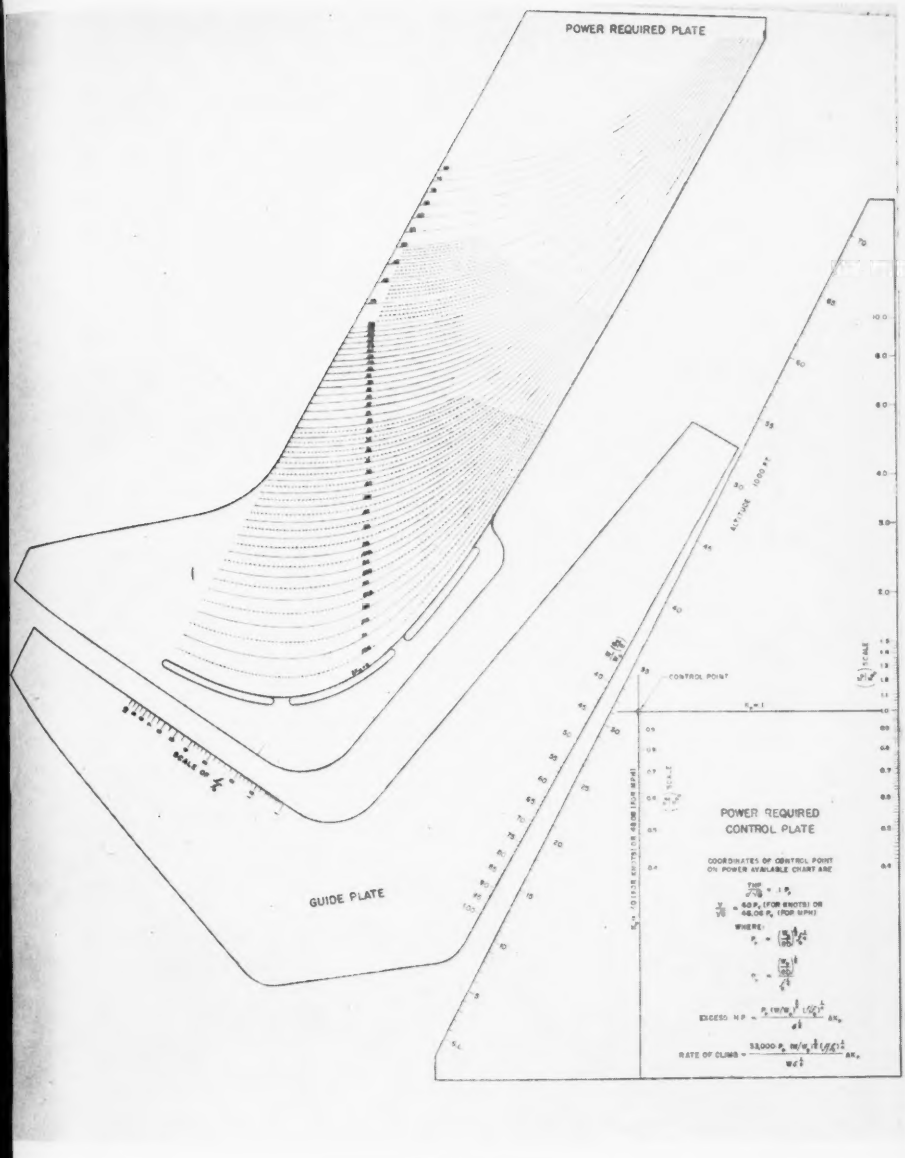


Fig. 2.
Performance analysis plates.

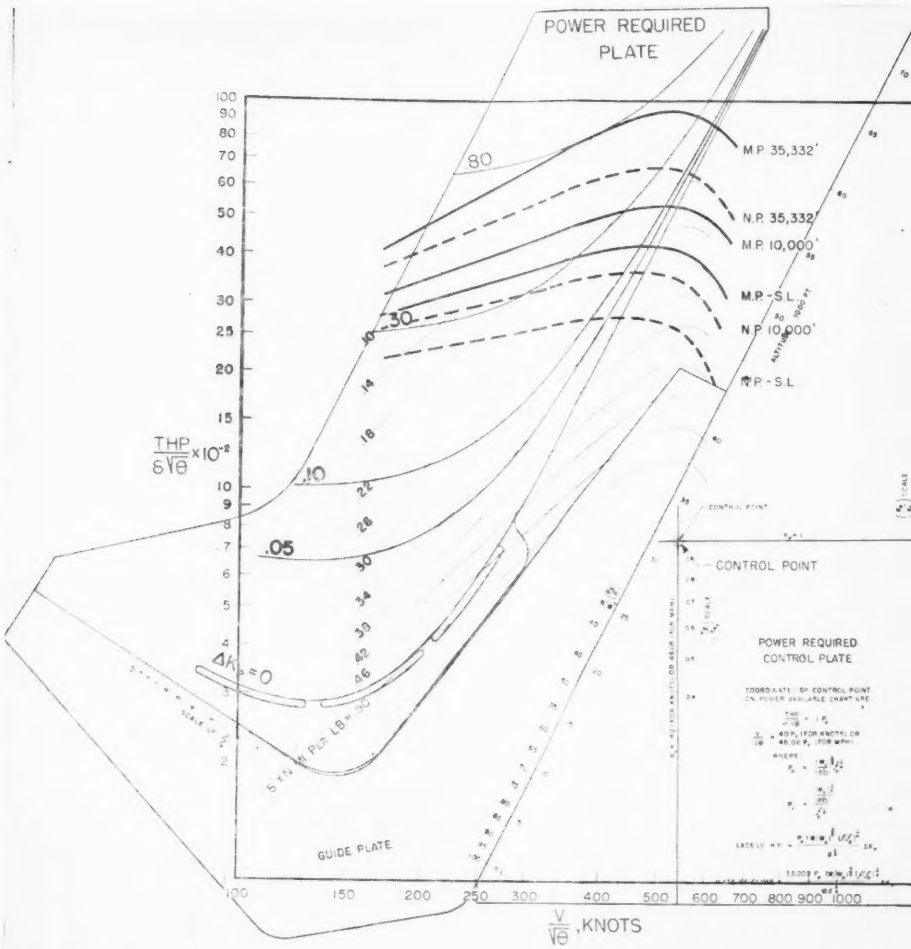
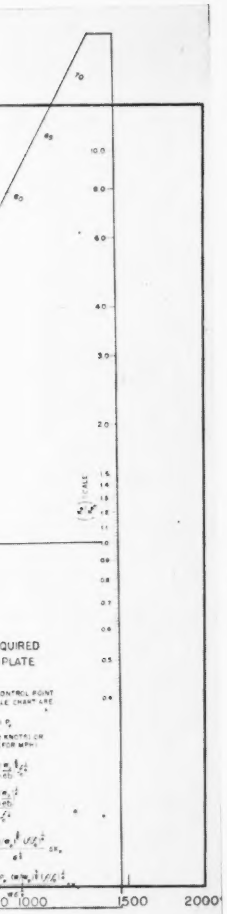


Fig. 4.
Illustration of Performance analysis procedure.


70
60
50
10.0
8.0
6.0
4.0
3.0
2.0
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
QUIRED
PLATE
1000
1500
2000

horsepower-available graph is normally plotted on an assumption of 100 per cent. ram recovery at the inlet to the compressor so as to allow greater flexibility in correcting for duct losses. Similarly, corrections for increased tail pipe losses may be made by this method.

When using these scales, the following points are to be observed:

1. Values of $V/\sqrt{\theta}$ for high speed, climbing speed and speed for best range are all correct since no change has been made in velocity scales.

2. The value of ΔK_p is correct and when multiplied by the original value of P_p used in plotting the Control Point will give the correct rate of climb.

3. However, the mileage ($\delta \times$ n.mi./lb.) must be corrected by dividing by the ratio K_p/K_{p_0}, if there is no change in engine efficiency, which is the case if the power plant size is being increased or decreased or if multiple engines are to be employed. Since duct or tail pipe losses not only decrease the thrust horsepower but increase the specific fuel consumption, the mileage, as determined from the logarithmic solution must be divided by the product of K_p/K_{p_0} times the ratio s.f.c./$(\text{s.f.c.})_0$. This principle may also be employed to correct for changes in combustion efficiency, by dividing the mileage by the ratio η_b/η_{b_0} (η_{b_0} being the original value of combustion efficiency used in plotting the chart).

From this discussion and description of this logarithmic method of performance analysis it is evident that the procedure is extremely flexible and therefore can account for all of the variables that may be encountered in the performance analysis of any aeroplane. This flexibility extends to the analysis of a series of aircraft which it may be necessary to study before deciding upon any one design. Since any series or any number of aircraft will be represented by various values of weight, span and parasite area and since these qualities combine in the two parameters, one for speed and one for power, which are in turn used to determine the Control Points plotted on the power-available chart, these Control Points then, also, describe a series of aircraft. By locating such a series of points, it is then possible to rapidly determine the variation of any or all items of performance between a series of designs or variations of any one design. This was the primary reason for the development of this method and it has, indeed, proved useful. Another division in the Bureau of Aeronautics which is concerned with the performance analysis of aircraft proposed by the various contractors and with keeping up to date the performance characteristics of aircraft under procurement, as revisions are made, has now adopted this system as a means of saving time. It finds that the answers obtained are identical with its older methods which required the computation and plotting of power-required and available curves at a series of altitudes. Small changes in weight or in parasite drag require the re-calculation and re-plotting of additional curves, while with this system, a change in the co-ordinates of the Control Point may be accomplished by simple proportion, if the change is to be recorded. If no record is required, the weight and parasite scales of the power-required overlays will suffice.

The power-available chart for either the turbo-prop or the turbo-jet is constructed with no allowance for change in component efficiencies or losses of combustion efficiency with altitude. These losses must be considered, if present, when computing range. A suggested means for making combustion efficiency correction will be discussed later, and variations of component efficiencies with altitude will also be investigated.

Each designer will have his own methods for estimating the aircraft polar and consequently of obtaining f and e for use with the analysis already described. For first estimates before a design has reached the complete layout stage it is often desirable to employ approximate methods to estimate these quantities. This is particularly true when studying a large series of possible aircraft in order to reach a thorough understanding of a given problem.

An analysis of flight test data of a number of existing aeroplanes seems to provide such an approximate means for obtaining f and e. It is probable that the parasite drag of the modern, smooth and well faired aeroplane is largely skin friction. Fig. 7 is a graph of f *versus* total surface area of a number of aircraft. From this figure, it is apparent that the jet aeroplanes group very well around a single line of constant surface drag coefficient equal to 0.003. The reciprocating-engined aircraft appear to have higher values of this coefficient, as would be expected.

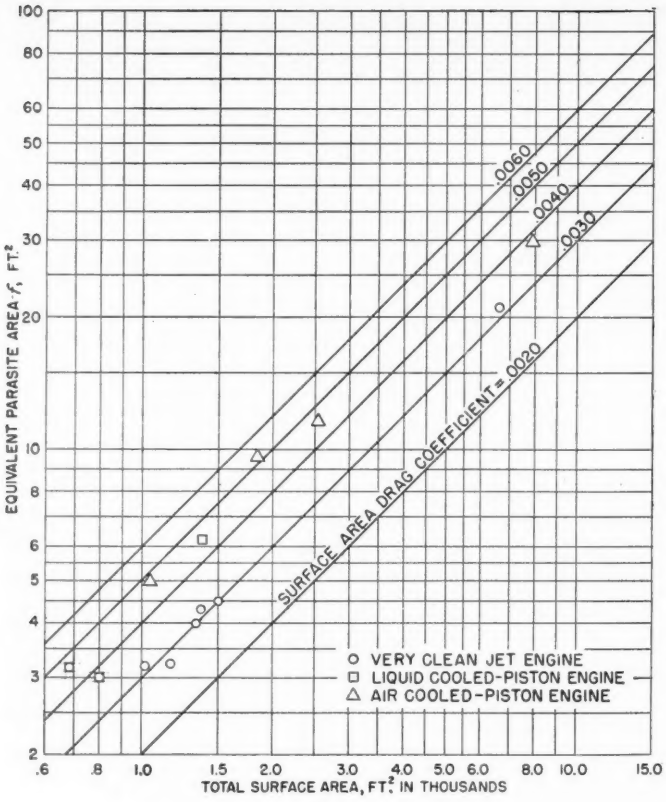


Fig. 7.
Variations of f with wetted area.

Similarly, Fig. 8 shows values of e obtained from flight tests of a number of aircraft. It will be noted that, in the majority of cases, the experimental points plot fairly consistently along the curves shown. When we consider the large number of variables that may affect e, probably no better agreement can be expected. Further analysis, considering wing taper ratio and thickness ratios at the root and tip, might add greater accuracy to this graph but there are many other factors that cannot be as simply expressed that will likewise affect e. For preliminary estimates, it appears that this figure will provide a rational basis of estimation, at least.

The system outlined may appear somewhat cumbersome in its mechanical aspects due to the use of three separate transparent overlays. The Research Division has experimented with both a single transparent power-required overlay and a system using a two unit plate. It has been found that the three unit method saves the greatest computational time and is less liable to error.

The example Thrust Horsepower curves of Fig. 3 represent a turbo-prop engine. Any other power plant type might have been chosen for illustrative purposes. Turbo-jet, reciprocating engine or rocket power can be shown equally well on the logarithmic graph. Naturally, there is a difference in the shape and location of the curves for the other engines.

Furthermore, the whole procedure might be based upon Thrust rather than upon Thrust Horsepower. In this case, the Speed Parameter is the same as given in

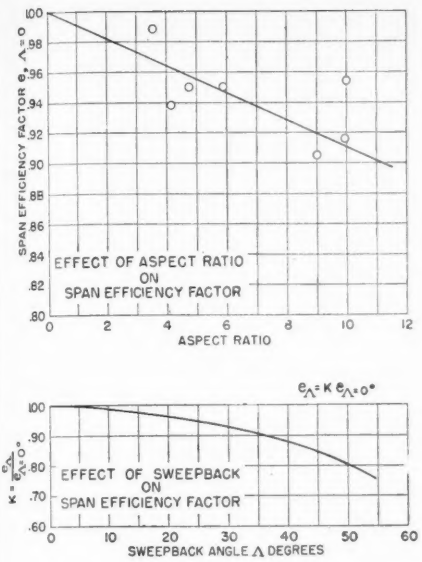

SPAN EFFICIENCY FACTOR $e_{\Lambda=0}$
EFFECT OF ASPECT RATIO ON SPAN EFFICIENCY FACTOR
ASPECT RATIO
$e_\Lambda = K\, e_{\Lambda=0°}$
$K = e_\Lambda / e_{\Lambda=0°}$
EFFECT OF SWEEPBACK ON SPAN EFFICIENCY FACTOR
SWEEPBACK ANGLE Λ DEGREES

Fig. 8.
Span efficiency.

Equation (5*a*) and a new quantity, a Drag or Thrust Parameter, P_D, is introduced. The algebraic expression for this parameter is

$$P_D = P_p / P_v = [(W_0)/(b\,e)]f^{\frac{1}{2}}$$

The generalised Thrust Required equation becomes

$$K_D = 0.0034\, K_v^2 + 94.1 / K_v^2$$

where

$$K_D = (D/\delta)/(P_D/\delta)$$

If desired the overlays may be re-plotted on a Drag and Thrust basis instead of Thrust Horsepower using the above equations. The Research Division prefers the system given because one set of overlays may be used for all engines and also the conversion from the power plant and propulsive system analysis of the next two Sections is more direct.

4. TURBINE ENGINE POWER GENERATOR

The data for plotting the thrust horsepower-available chart are obtained from the engine manufacturer in many forms but in general it is a simple matter to convert to the logarithmic co-ordinates. Some of the manufacturers are now submitting their estimated performance directly upon this chart, using sheets furnished by the Bureau of Aeronautics. The Research Division is

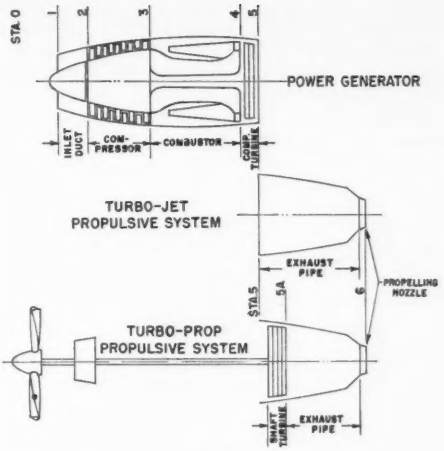


Fig. 9.

required, in many instances, to study new power plants to determine and suggest courses of action for future development. This requirement is similar to the preliminary design of aircraft as previously described. In making such studies, it has been found desirable to separate this general engine type into two parts, *i.e.* the Power Generator and the Propulsive system. Fig. 9 is a sketch which shows both a turbo-jet and a turbo-prop engine so divided and which defines the various stations in the engine coinciding with characteristic points on the ideal cycle diagram shown in Fig. 10.

This is the usual enthalpy-entropy diagram, drawn on the assumption of no internal losses or increase in entropy. It is convenient to divide this diagram into two parts by the isobar, p_{2T}, thus separating the turbine-compressor from the ram or velocity

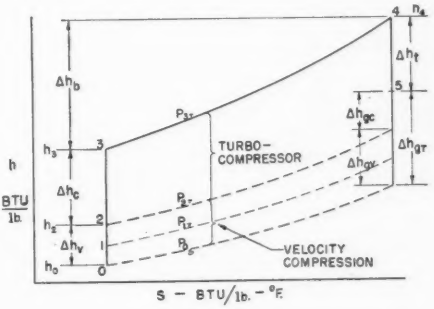


Fig. 10.

compression cycle. In Reference 2, it was demonstrated that if the ratio of specific heats were assumed constant and if the base for enthalpy determination is taken at 0° absolute, the ideal generator useful enthalpy from the turbo-compressor, Δh_{gc}, can be expressed as:

$$\Delta h_{gc} = \Delta h_c \left[(\Delta h_b)/(h_2 + \Delta h_c) \right] \quad (17)$$

Similarly, the ideal generator useful enthalpy, from the velocity compression cycle can be written as:

$$\Delta h_{gv} = \Delta h_v \left[\frac{\Delta h_b - \Delta h_{gc}}{(h_0 + \Delta h_v)} \right] \quad . \quad (18)$$

Then the total generator ideal useful enthalpy is given by the sum of these two quantities, that is

$$\Delta h_{gT} = \Delta h_{gc} + \Delta h_{gv} \quad . \quad (19)$$

It is convenient to introduce additional definitions at this point:

Let $\tau = 1 + \frac{1}{2} M_0^2 (\gamma - 1) = h_2/h_0 = 1 + \Delta h_v/h_0$. (20)

γ = Ratio of specific heats, 1.40 (at sea level temperatures) in this study.

and $h_0 = A\theta$

Then $h_2 = A\theta\tau$

and

$$\tau - 1 = \tfrac{1}{2} M^2 (\gamma - 1) = 0.00457 \left[V_0/(100\sqrt{\theta}) \right]^2 \quad . \quad . \quad . \quad . \quad (21)$$

where V_0 is in knots.

Inserting these definitions into Equations (17) and (18) and dividing by $\theta\tau$ we have

$$\left.\begin{aligned} \frac{\Delta h_{gc}}{\theta\tau} &= \frac{\Delta h_c}{\theta\tau}\left[\frac{\Delta h_b/(\theta\tau)}{A + \Delta h_c/(\theta\tau)}\right] \\ \frac{\Delta h_{gv}}{\theta\tau} &= \frac{\tau - 1}{\tau}\left[\frac{\Delta h_b}{\theta\tau} - \frac{\Delta h_{gc}}{\theta\tau}\right] \end{aligned}\right\} \quad (22)$$

or

$$\frac{\Delta h_{gv}}{\theta\tau} = \frac{0.00457}{\tau}\left[\frac{V_0}{100\sqrt{\theta}}\right]^2 \left\{ \frac{\Delta h_b}{\theta\tau} - \frac{\Delta h_{gc}}{\theta\tau} \right\} \quad . \quad . \quad . \quad . \quad (23)$$

Reference 3 gives the value of A as 28.464 B.Th.U./lb. at 59° F. computed from a base of 400° R. Correcting to a base of absolute zero by adding 96 B.Th.U./lb. gives the value of A used in this study as 124.464 B.Th.U./lb.

Since the ratio of specific heats, γ, does not remain constant at elevated temperatures

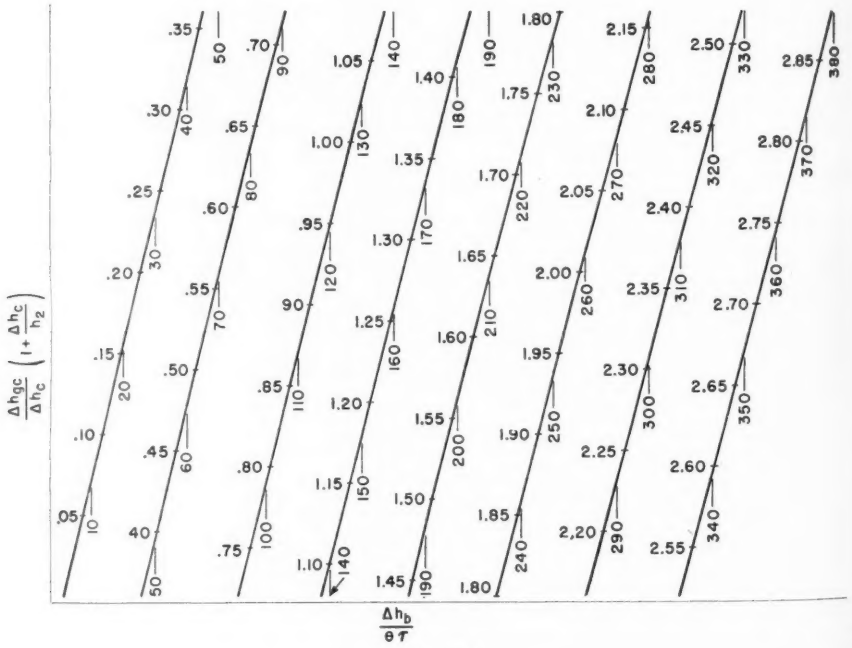


Fig. 11A.
Generator enthalpy of ideal turbo-compressor cycle.

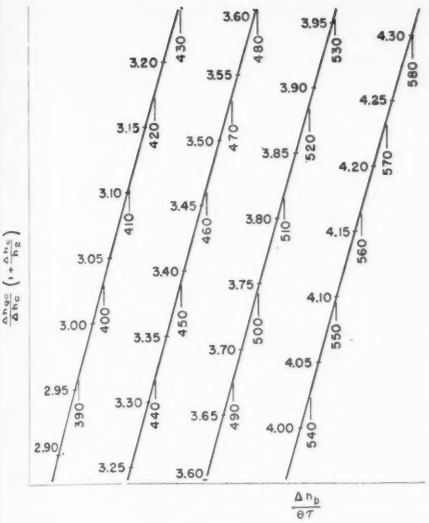


Fig. 11B.
Generator enthalpy of ideal turbo-compressor cycle.

and is affected by combustion products, Equations (22) and (23) cannot be used except for very rough analyses. However, by the use of the tables of References 3 and 4, computations for a great number of ideal cycles can be made and the results plotted in a manner consistent with these formulæ. Figs. 11 and 12 are the results of such an extensive analysis. The results are plotted as a folded line so as to attain greater accuracy. The effects of combustion products were ignored in this computation and checks made to determine the inaccuracy caused by this approximation. It was found that in no case did the correct value differ from the useful enthalpy obtained from these graphs by more than 2 per cent. at a fuel air ratio of 3 per cent. Thus, it is apparent that these curves may be employed with confidence for all engineering analyses.

The foregoing discussion has been concerned with the ideal cycle, which has little practical interest except as a step in a final solution in which losses are taken into account. The ideal cycle diagram of Fig. 10

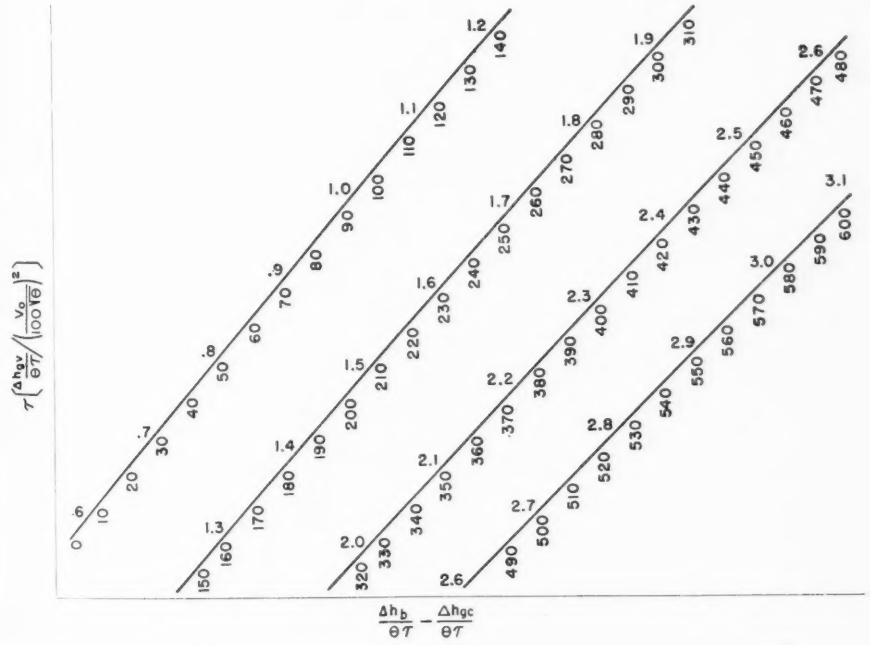


Fig. 12.
Expansion enthalpy of ideal velocity cycle.

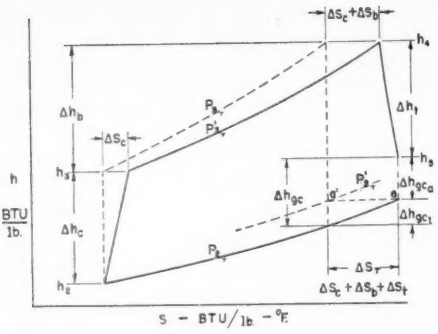


Fig. 13.

is repeated as dotted lines in Fig. 13 with a corresponding turbo-compressor cycle with losses shown. Since there can be no loss in energy, the enthalpy levels of each of the points of the cycle diagram prior to the final expansion remain the same as for the ideal cycle. The ideal generator enthalpy $\Delta\ h_{gc}$, has been reduced, however, by the quantity $\Delta\ h_{gcl}$ as shown. This has been caused by a series of entropy increments through the compressor, burner and turbine which have displaced the point of discharge to the initial pressure farther to the right along the p_2 isobar.

If point a, the final discharge enthalpy is projected to the left to intersect the ideal isentropic at point a', this point will define a new isobar having a higher pressure than p_{2T}. This same isobar, p_{2T}', might be obtained if the generator were subjected to greater pressure at the exit of the turbine than at the compressor inlet.

In the case of the velocity cycle a final isobar lower than p_{2T} gave an increase in enthalpy and conversely this hypothetical isobar, p_{2T}', will decrease the total power available. It may be considered, therefore, that the generator is subject to an imaginary velocity which reverses the sign of the $[V_0/(100\sqrt{\theta})]^2$ term of Equation (23). Thus, Fig. 12 may be used to determine the value of $\Delta\ h_{gcl}$ if a relation between the total entropy increment through the generator and this imaginary velocity is found.

At constant enthalpy

$$\Delta S = -(R/J)\log_e(p_2/p_1) \quad . \quad (24)$$

and

$$\frac{p_{2T}}{p_{0s}} = \left[1 + 0.00457\left(\frac{V}{100\sqrt{\theta}}\right)^2\right]^{\gamma/\gamma-1}$$

for velocity compression.

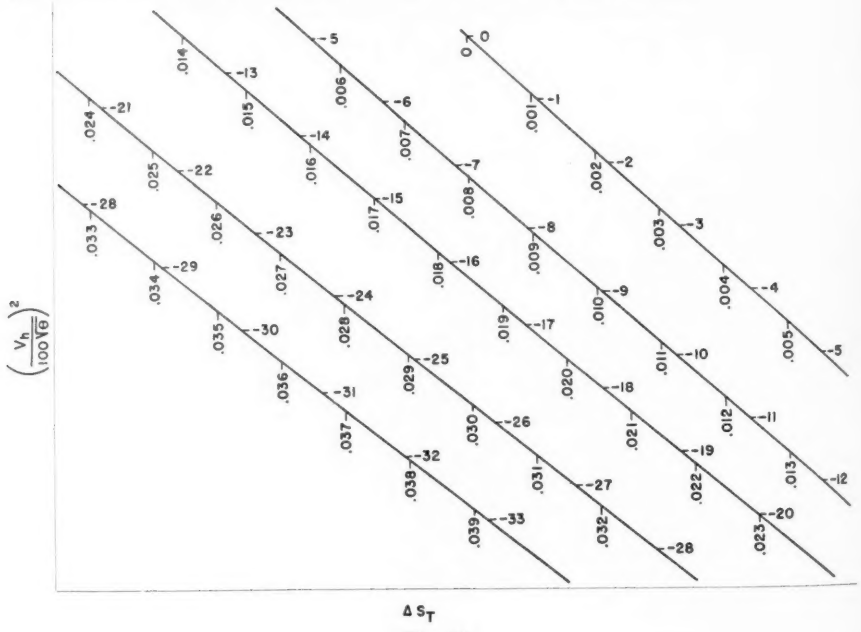


Fig. 14.
Hypothetical velocity produced by entropy increase.

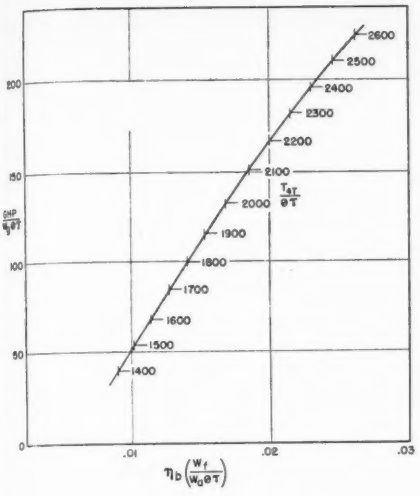


Fig. 15.
Generator gas horsepower.

Then

$$\Delta S = -C_p \log_e \left[1 + 0.00457\left(\frac{V}{100\sqrt{\theta}}\right)^2\right] \quad (25)$$

Denoting the left member of this equation as the total value of ΔS_T, obtained by summing up all small increments and solving for V gives for the value of this hypothetical velocity factor

$$\left[\frac{V h}{100\sqrt{\theta}}\right]^2 = 2.190 \times 10^2 \left[(1/e^{\Delta S_T/C_p}) - 1\right] \quad (26)$$

Figure 14 gives the solution for Equation (26) with the value of C_p taken as 0.240. Then with ΔS_T known, the loss in generator power due to the inefficiency of the components can be readily determined from Fig. 12.

It appears that the use of polytropic efficiency is more convenient than adiabatic efficiency when determining the entropy increments of the various components.

If n = polytropic exponent
γ = ratio of specific heats

then $\eta_{pc} = \dfrac{\gamma - 1}{\gamma} \Big/ \dfrac{n-1}{n}$ for the compressor

and $\eta_{pt} = \dfrac{n-1}{n} \Big/ \dfrac{\gamma - 1}{\gamma}$ for the turbine.

The entropy increments then become

$$\Delta S_c = C_{pa}(1 - \eta_{pc}) \log_e (1 + \Delta h_c / h_2) \quad (27)$$

$$\Delta S_t = C_{pg}(1 - 1/\eta_{pt}) \log_e (1 - \Delta h_t / h_4) \quad (28)$$

C_{pa} = specific heat of air at constant pressure

C_{pg} = specific heat of mixture of air and combustion products at elevated temperature and constant pressure.

Reference 2 discusses a means for estimating the total pressure loss through the combustion chamber and this value can be converted to entropy by Equation (29).

$$\Delta S_b = -0.06854 \log_e (1 - \Delta p_b / p_3) \quad (29)$$

With these equations evaluated, ΔS_T is found from

$$\Delta S_T = \Delta S_c + \Delta S_b + \Delta S_t \quad . \quad (30)$$

Thus it is apparent that with the use of Figs. 11, 12 and 14 a rapid estimate can be made for the generator enthalpy at any set of design conditions, defined by Δh_c and Δh_b, when the losses through the engine are known or assumed. Furthermore, the increment in enthalpy due to ram can be determined quickly. These graphs have been of great assistance in estimating the performance at design point of new turbine power plants.

A graphical representation of the complete generator performance may be shown on three curves as shown on Figs. 15, 16 and 17, with any assumed control programme.

When converting $\Delta h_g/(\theta\tau)$ and $\Delta h_b/(\theta\tau)$ to the co-ordinates of Fig. 15 the following equations are used.

$$\frac{G.H.P.}{W_g \theta \tau} = \frac{1.415}{1 + W_f/(W_a \theta\tau)} \frac{\Delta h_g}{\theta \tau}$$

$$\frac{W_f/W_a}{\theta \tau} = \frac{\Delta h_b/(\theta\tau)}{18840\,\eta_b - \Delta h_c/(\theta\tau) - \Delta h_b/\theta\tau} \quad (31)$$

η_b = combustion efficiency.

The value $[V_D/(100\sqrt{\theta})]^2$ is used to account

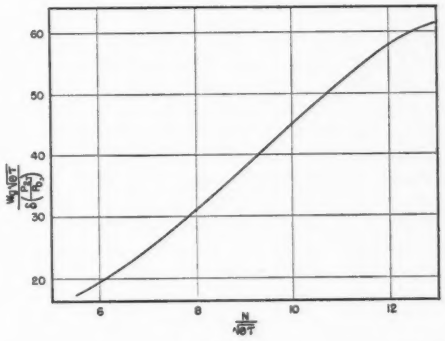


Fig. 16.
Gas flow.

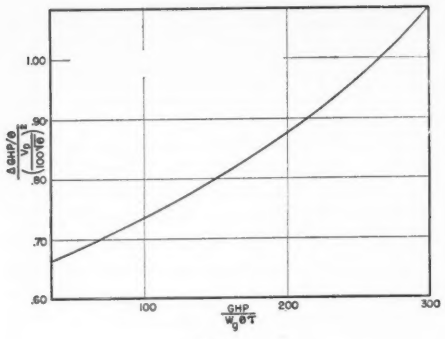


Fig. 17.
Increment in gas horsepower produced by velocity cycle.

for any losses in total pressure in the inlet ducts following a reasoning exactly similar to that used in developing the hypothetical velocity for internal losses. This quantity is defined as

$$\left(\frac{V_D}{100\sqrt{\theta}}\right)^2 = 219.5\,\tau \times \left[1 - \left\{\tau^{3.5} - \frac{\Delta p_{T_{1\cdot0-2}}}{p_{0s}}\right\}^{-0.286}\right]. \quad (32)$$

Fig. 18 is a solution to this equation.

In order to construct the curves similar to Figs. 15, 16 and 17 for a new engine, we first estimate the performance at the design point discussed previously. In order to estimate the power variation off this single point, the complete generalised performance of Reference 2 is utilised. In this report, generalised compressor and turbine curves were matched and the generator useful enthalpy and air flow determined for ideal compression ratios from 2.186 to 17 ($\Delta h_c/h_2$ from 0.25 to 1.25) at design point. By assuming a relationship between the total temperature at station 4 and the revolutions of the turbine and compressor, it is possible to define a control programme and to draw an operating line across these generalised curves which will connect all the variables. It is assumed here that the peak cycle temperature at station 4 is related to the revolutions by the following parabolic equation

$$\frac{T_{4T}}{\theta\tau} = K\left(\frac{N}{\sqrt{(\theta\tau)}}\right)^2 \quad . \quad (33)$$

K = numerical factor.

Investigations have shown that this equation gives very nearly an optimum operation and provides a good margin of safety below compressor surge. At full power and high altitude, this relation accurately expresses the operating condition.

From this assumption the variations in enthalpy and gas flow were determined and the results are shown in Figs. 19 and 20. With these last curves we can now define the generator performance off the design point to a very reasonable degree of accuracy. The correction curve corresponding to Fig. 17 is computed directly from Fig. 15 after the generator fuel flow chart has been drawn, using the method already outlined.

The foregoing analysis has achieved some simplicity by not considering the peak cycle temperature T_{4T} as a parameter. However, this quantity does affect the turbine structural strength and therefore may be considered an operational limit along with the r.p.m. This was the reason for connecting these two quantities by the assumed control operation. Thus, this temperature must be obtained and indicated as shown in Fig. 15. Fig. 21 shows the relationship between temperature and enthalpy for a series of fuel air ratios. Fig. 22 gives the variation of Δh_c off design point which, when added to Δh_b and h_0 (124.464 B.Th.U./lb. static) gives the

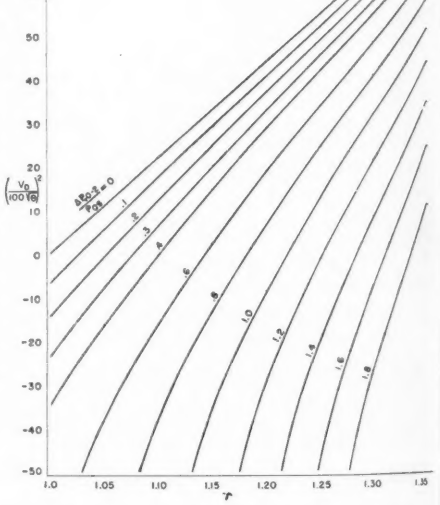


Fig. 18.
Velocity equivalent of duct losses.

enthalpy at station 4 and then with the fuel air ratio found, the temperature can be determined and plotted.

When computing the entropy increment through the turbine for a turbo-jet $\Delta h_t/(\theta\tau)$ is assumed to be equal to $\Delta h_c/(\theta\tau)$. The difference in mass flow caused by injecting fuel will account approximately for power absorbed by bearing friction and accessories. In Equation (28) the specific heat of the gas is taken at the design fuel air ratio and at the mean of the temperature range over which the turbine operates.

For a turbo-prop engine, a greater expansion takes place through the turbine than for a turbo-jet. Thus, greater power is removed and $\Delta h_t/(\theta\tau)$ no longer equals $\Delta h_c/(\theta\tau)$. Therefore, before Equation (28) can be used to determine the entropy increment through the turbine, the total value of $\Delta h_t/(\theta\tau)$ must be chosen. In making this choice, there are a number of factors that must be considered; the difference between the total turbine and the compressor powers must be no greater than the useful generator power under all conditions, otherwise an imaginary exhaust velocity will be obtained; the maximum possible thrust horsepower should be obtained from the combination of the propeller and exhaust jet; and consideration should be given to tail pipe burning of additional fuel for thrust augmentation at very high speeds.

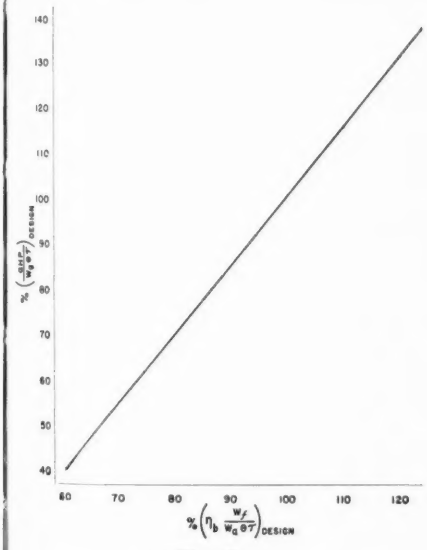


Fig. 19.
Generator power variation off design point.

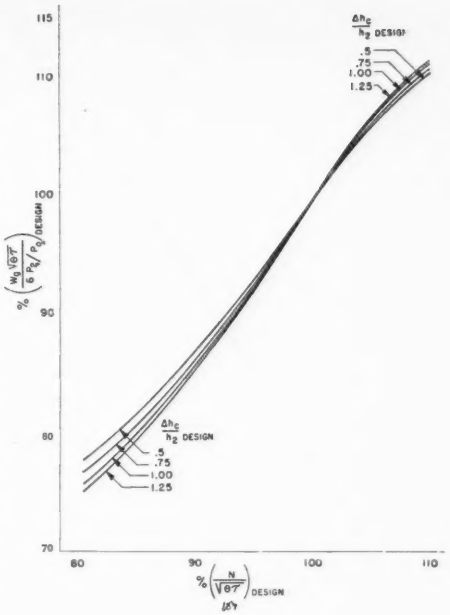


Fig. 20.
Gas flow variation off design point.

It seems that the choice of the ratio between the shaft power and jet power must be left to a separate study which considers these points and endeavours to obtain the best compromise between them. The Research Division makes the following assumptions in such studies:

(*a*) Variable area exhaust nozzles will be provided.

(*b*) All of the increase in power from the velocity cycle is added to the jet power, that is $\Delta h_t/(\theta\tau) - \Delta h_c/(\theta\tau)$ is a single valued function of $W_f/(W_a\,\theta\tau)$, unaffected by ram.

(*c*) The total generator power is obtained in the same manner as for a turbo-jet after the additional turbine entropy has been found.

(*d*) The shaft power is a constant percentage of the static generator power and the jet power, the remainder of the total power, and is affected by ram.

(*e*) A constant gear efficiency between 97 per cent. and 98 per cent. is assumed.

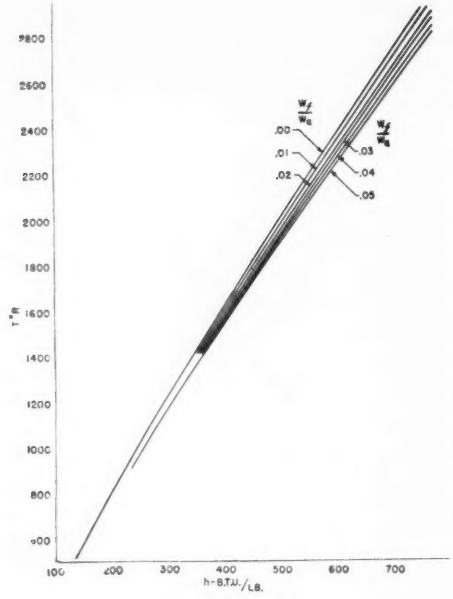


Fig. 21.
Temperature versus enthalpy for various fuel air ratios.
$H/C = 0.17647$.

The analysis of a turbo-prop engine will be illustrated later in this section. This will clarify the suggested procedure. Fig. 23 repeats the graph of Fig. 15, showing the division of power between the shaft and jet.

$$\frac{\text{S.H.P.}}{W_g\,\theta\,\tau} = \eta_g\,\beta\,\frac{\text{G.H.P.}}{W_g\,\theta\,\tau} \qquad (34)$$

β = Numerical factor

η_g = Gear efficiency

and

$$\frac{\text{Jet H.P.}}{W_g\,\theta\,\tau} = (1-\beta)\frac{\text{G.H.P.}}{W_g\,\theta\,\tau}$$

It is realised that there are many questions that may not have been answered by the foregoing discussion. Variations in specific heat with temperature have been ignored when dividing all values by the temperature ratio, $\theta\,\tau$, and possible increase in the internal pressure losses caused by a decrease in Reynolds number at altitude have not been considered. Furthermore, the analysis has been based upon the characteristics of air with no consideration of the effects of the products of combustion upon the specific heats. In order to investigate these factors, altitude wind tunnel tests of an existing turbo-jet engine were analysed. The test data was given in such a form that the efficiency of combustion could be computed and the fuel air ratio corrected by this factor. The results of this analysis are shown on Figs. 24 and 25. In all, there are 111 test runs represented on this chart covering altitudes from 5,000 to 40,000 feet and Mach numbers from 0.23 to 1.08. The corrections for velocity were obtained from Fig. 12. Considering all the computations that were required to reduce these data the grouping of the points is remarkable.

These tests provided information from which the total increase in entropy through the generator might be obtained so an analysis was made using the off design point charts of Figs. 19 and 20. Figs. 26 and 27 show the resulting graphs compared with test points. This check shows excellent agreement so it seems that a reasonably accurate means for estimating turbo-compressor generator performance is provided by the methods suggested in this section and tends to remove doubt as to the validity of the assumptions made.

This analysis has been concerned with the straight simple cycle turbo-compressor

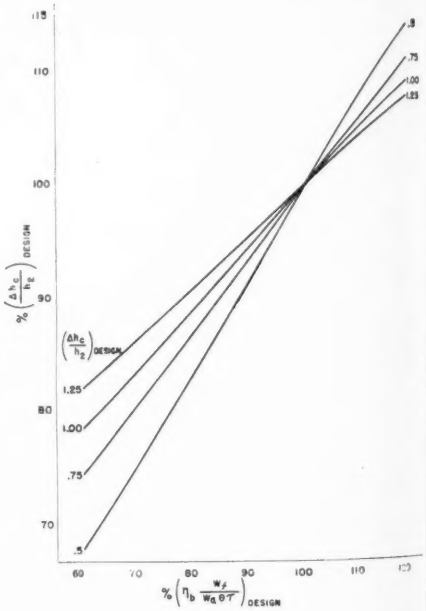


Fig. 22.
Compressor enthalpy variation off design point

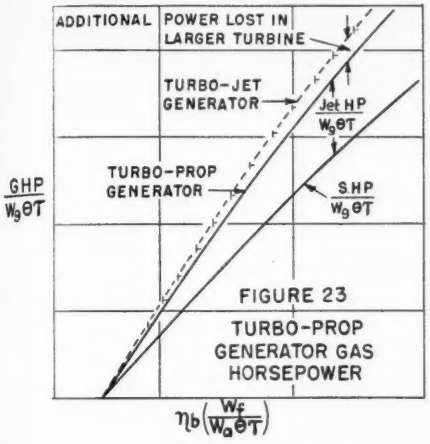


Fig. 23.
Turbo-prop generator gas horsepower.

generator with ram, but the same methods may be applied to other cycles. For example, a ram jet is a velocity cycle engine only and consequently Fig. 12 will give the ideal generator power with proper interpretation of the abscissa of that graph. Similarly, tail pipe burning may be considered to be a velocity cycle with the inlet ram pressure caused by a velocity equal to the nozzle velocity of the turbo-compressor cycle, again with proper interpretation of the abscissa of Fig. 12. It is probable, however, that corrections to the results will be required since the peak temperatures are much higher for these cycles than for the turbo-compressor unit. Also, the fuel air ratios are much greater. Therefore, disregarding the effects of combustion products upon the specific heat may introduce considerable error. Furthermore, the effects of dis-association must be considered when determining peak temperatures. If Fig. 12 is used for the analysis of either the ram jet or the after-burning cycle, the abscissa of this graph then becomes the maximum enthalpy at the peak of the cycle less 124.464 B.Th.U./lb., since $\Delta h_b/(\theta\tau) - \Delta h_{gc}/(\theta\tau)$ may be shown to equal the above quantity for the velocity cycle previously analysed.

Other cycles with inter-burning, inter-cooling or heat exchange between tail pipe and combustor inlet air also may be analysed by similar methods to those employed for the simple engine. In fact, the graphs of Figs. 11 and 12 may be used for this purpose by proper transformation of the co-ordinates.

Before the altitude performance of an engine can be considered to be completely defined, some estimate must be made for the efficiency with which the combustion process is carried out. Tests of full-scale engines in an altitude wind tunnel, as well as separate combustor tests, have shown a decrease in the heat obtained from a fixed fuel air ratio as the altitude is increased. Also, an altitude may be reached where burning is no longer possible. Analyses of the test results on a few units have shown that the combustion heat losses may be shown graphically as a function of the absolute total pressure and temperature of the air entering the combustion chamber at station 3. Since these two variables also control the air density, it is probable that the velocity at station 3 should also be considered. Unfortunately, so few tests are available with widely different combustor inlet areas per unit mass flow that it was impossible to include effects of this additional variable. Since any given design of chamber probably will obey the same general laws, it appears that a ratio expressing the decrease in efficiency should remove the effects of inlet velocity at the point of best efficiency, which must be estimated separately, and also to account for the variation in that velocity with changes in total pressure and temperature, as combustor inlet areas are constant for any given engine.

A graphical presentation of results obtained by testing a portion of an old type annular combustor is given in Reference 2. These data show the ratio $\eta_b/\eta_{b\,max}$ plotted against the product of the total pressure and total temperature at the chamber inlet with fuel air ratio as a parameter. This type of graph records test data in a reasonable manner, but is not entirely satisfactory for use with the logarithmic performance analysis procedure given in the first Section. An empirical formula expressing the data shown in Reference 2 and tests of additional burners of improved characteristics can be derived, however. This expression is more usable for aircraft performance analysis.

The empirical formula that seems to fit the test data with sufficient accuracy is given by Equation (35).

$$\eta_b = 1 - e^{\alpha\,(p_{3T}T_{3T})}\left(\frac{W_f}{W_a}\right)^{\zeta} \Big/ (1.095\times 10^6) \quad (35)$$

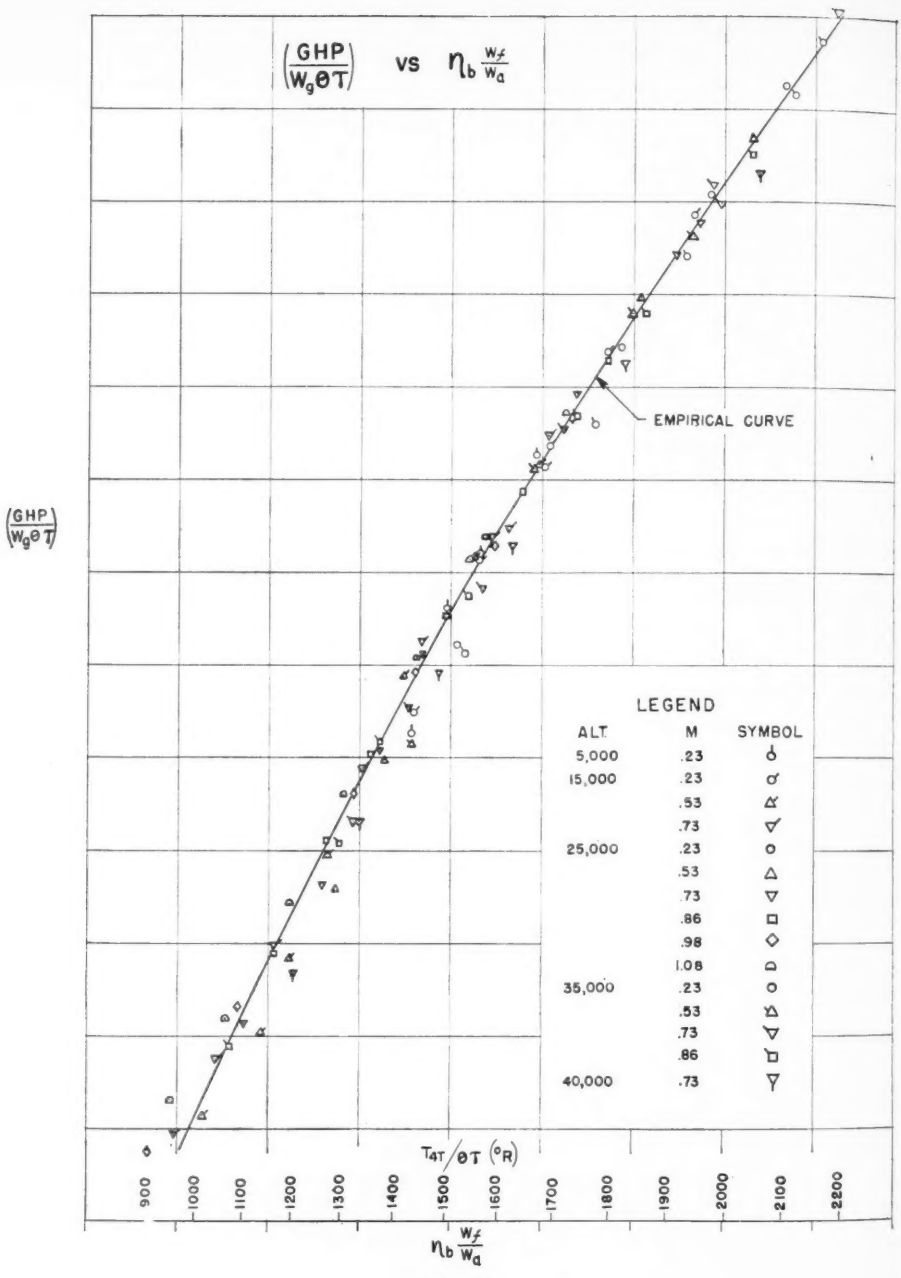


Fig. 24.
Generator horsepower test data.

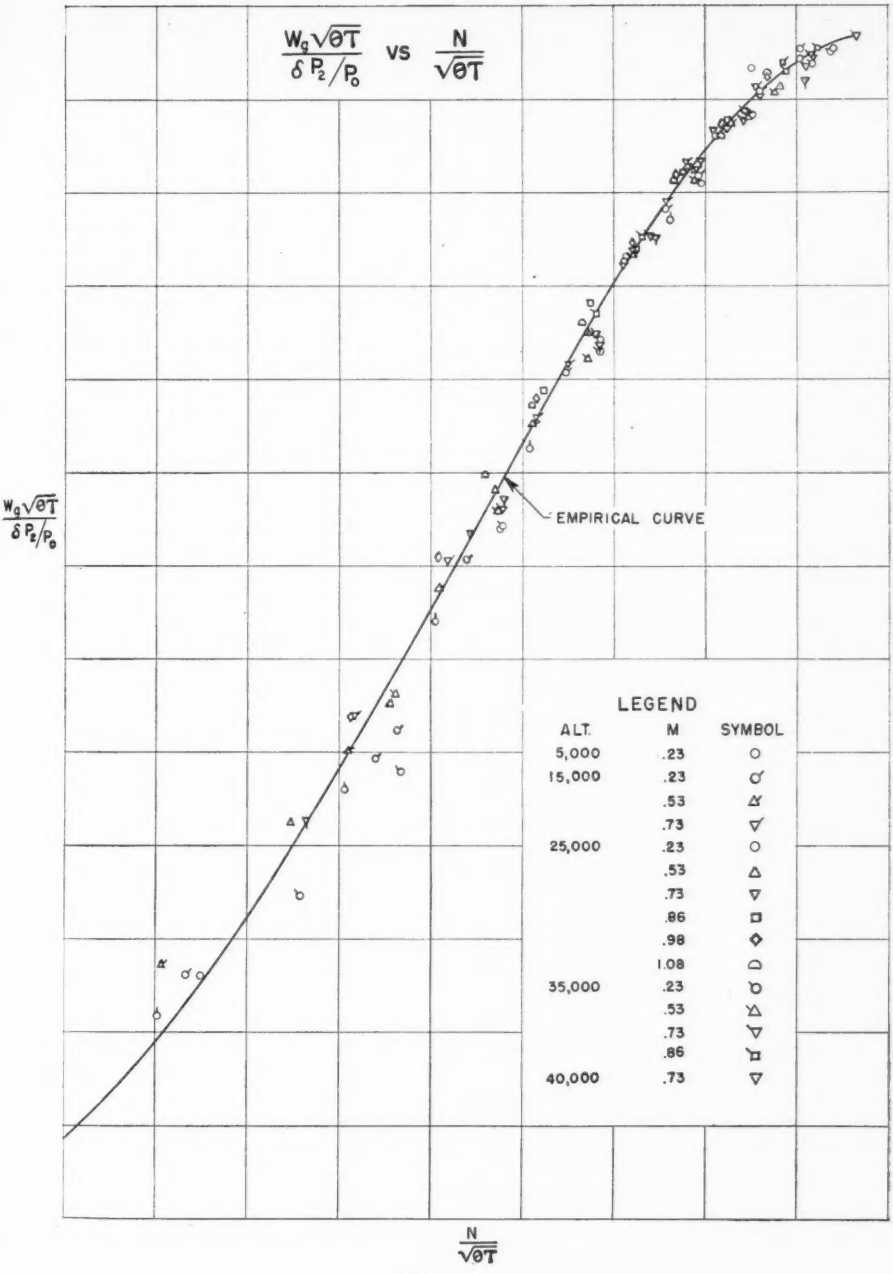


Fig. 25.
Gas flow—test data.

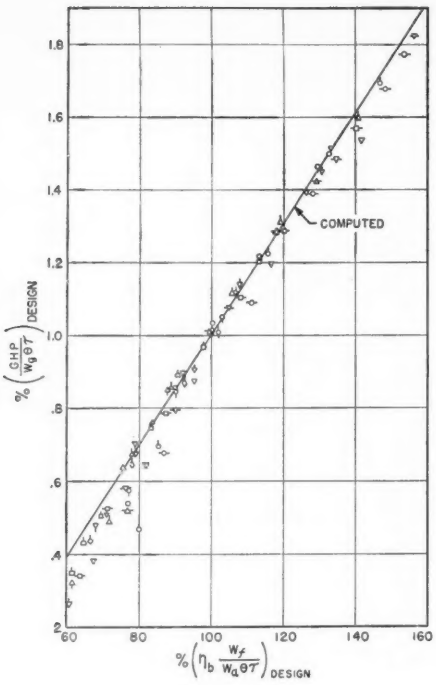


Fig. 26.
Generator performance comparison, computed and test.

The two empirical exponents α and ζ have been found to have the following values:

Early type of annular combustor, $\alpha = -15.35$, $\zeta = 0.51$

Improved type annular combustor, $\alpha = -1349.0$, $\zeta = 1.50$

Excellent can type combustor, $\alpha = -186.5$, $\zeta = 0.735$

It may be demonstrated that

$$p_{3T}\, T_{3T} = 1.095 \times 10^6\, \delta\theta\tau^{4.5}\, (1 + \Delta h_c/h_2)^{1.5}\, \eta_c \quad . \quad (36)$$

where

η_c = Pressure efficiency of inlet duct and compressor combined.

Substituting (36) into (35) gives

$$\log (1 - \eta_b) = \alpha\, \delta\, \theta\, \tau^{4.5} \left(1 + \frac{\Delta h_c}{h_2}\right)^{4.5} \times \times \left(\frac{W_f}{W_a}\right)^{\zeta} (\theta\tau)^{\zeta}\, \eta_c$$

or

$$\log (1 - \eta_b) = \alpha\, \delta\, \theta^{1+\zeta}\, \tau^{4.5+\zeta} \times \times \left(1 + \frac{\Delta h_c}{h_2}\right)^{4.5} \left(\frac{W_f}{W_a}\right)^{\zeta} \eta_c \quad (37)$$

The terms in Equation (37) may be divided into two groups, one dependent upon the external conditions under which the engine is operating and the other upon the engine and combustor combination.

Let

$$x = \alpha\, \eta_c \left(1 + \frac{\Delta h_c}{h_2}\right)^{4.5} \left(\frac{W_f}{W_a}\right)^{\zeta}$$

$$y = \delta\, \theta^{1+\zeta}\, \tau^{4.5+\zeta}$$

Then $\log_e (1 - \eta_b) = x\, y$

and $\eta_b = 1 - e^{xy}$. (38)

At the design point the value of η_c is given by Equation (39).

$$\eta_c = e^{-14.6\,(\Delta S_c + \Delta S_D)} \quad . \quad . \quad . \quad (39)$$

ΔS_c = Entropy increment through compressor

ΔS_D = Entropy increment through inlet duct.

Little error is introduced if this value is assumed constant throughout the operating range.

Thus it is possible to estimate the efficiency of combustion when the characteristics of

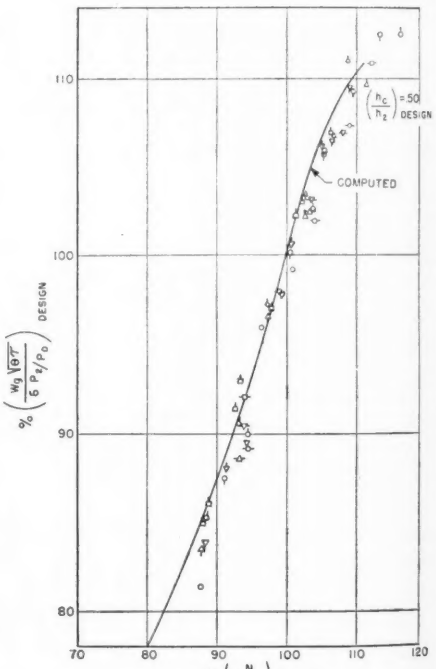


Fig. 27.
Gas flow comparison, computed and test.

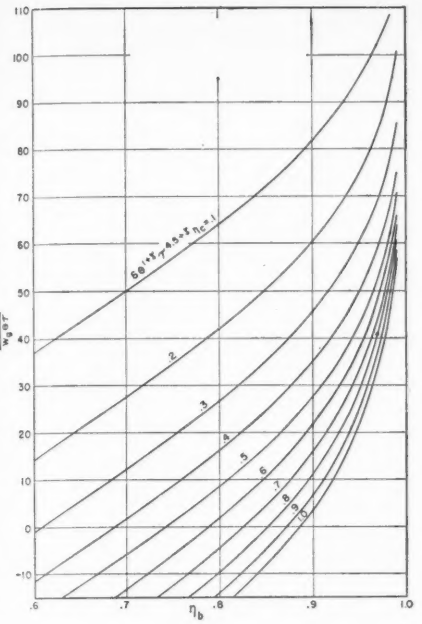


Fig. 28.
Combustion efficiency test data.

any burner are known. It is convenient to calculate the value of the parameter x with y assumed equal to one, as part of the generator characteristics, then when the generator power has been converted to thrust horsepower at a series of velocities to include the τ term in the parameter y and then to plot the results for a series of values of $\delta\theta^{1+\zeta}$ against thrust horsepower. This allows direct use at any point on the logarithmic graphs. For illustrative purposes the combustion efficiency data employed in the analysis leading to Fig. 24 is plotted on Fig. 28 as η_b against generator specific power.

This is a more useful presentation of combustion efficiency data for our purpose than that shown in Reference 2, although the latter may be a perfectly satisfactory means of plotting general data taken from isolated combustor tests. The data for other generators may be plotted in a similar manner either from direct engine tests or Equation (39) may be employed, using a value of ζ given above or any other number obtained from analysis of other combustor tests.

In closing this Section, a complete example will be calculated in order to clarify the rather involved reasoning and to act as a guide for anyone wishing to perform a similar analysis.

Assumptions—Turbo-jet.

$\Delta h_c/h_2 = 1.00$, at design point,

$\Delta h_b/(\theta\tau) = 271$ B.Th.U./lb.

$\eta_{pc} = 0.90$, $\eta_{pt} = 0.93$, $\frac{\Delta p_{3-4T}}{p_{3T}} = 0.015$

$\eta_b = 0.99$, $\frac{W_a\sqrt{(\theta\tau)}}{\delta\, p_{2T}/p_{0s}} = 120$ lb./sec.

Analysis

$h_3/(\theta\tau) = 124.464 \quad (1 + \Delta h_c/h_2)$
$= 248.93$ B.Th.U./lb.

$h_4/(\theta\tau) = 248.93 + 271 = 519.93$ B.Th.U./lb.

From Equation (31), $\eta_b \frac{W_f}{W_a\theta\tau} = 0.01472$.

From Fig. 21 at 519.9 B.Th.U./lb. and $W_f/(W_a\theta\tau)$ of 0.01472

$T_{4T} = 2010°$R, $\theta\tau = 1.00$

From Fig. 11A at $\Delta h_b/(\theta\tau) = 271$

$(\Delta h_{gc}/\Delta h_c)(1 + \Delta h_c/h_2) = 2.092$

Then Δh_{gc} (ideal) $= \frac{2.092 \times 124.46}{1+1}$
$= 130.11$ B.Th.U./lb.

From Equation (27)

$\Delta S_c = 0.24\ (1 - 0.90)\ \log_e\ (1+1)$
$= 0.016625$ B.Th.U./lb.°R.

From Equation (28)

$$\Delta S_t = 0.2805\left(1 - \frac{1}{0.93}\right)\log_e\left(1 - \frac{124.46}{519.9}\right)$$
$= 0.00576$ B.Th.U./lb.°R.

$C_{pg} = 0.2805$ at 0.0147 fuel air ratio and mean temperature.

From Equation (29)

$\Delta S_b = -0.06854 \log_e [1 - 0.015]$
$= 0.001034$ B.Th.U./lb. °R.

Therefore

$\Delta S_T = 0.016625 + 0.00576 + 0.001034$
$= 0.023419$ B.Th.U./lb.°R.

Then from Fig. 14

$$\left(\frac{V_h}{100\sqrt{\theta}}\right)^2 = -20.3$$

$\frac{\Delta h_b}{\theta\tau} - \frac{\Delta h_{gc}}{\theta\tau} = 271 - 130.11$
$= 140.89$ B.Th.U./lb.

From Fig. 12

$$\tau\left[\frac{\Delta h_{gv}}{\theta\tau}\right] \Big/ \left(\frac{V_0}{100\sqrt{\theta}}\right)^2 = 1.21.$$

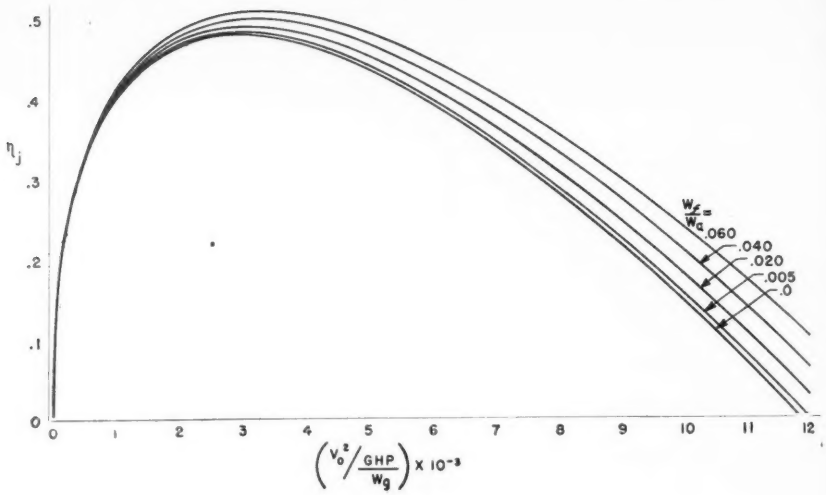


Fig. 29.
Propulsive efficiency of jet.

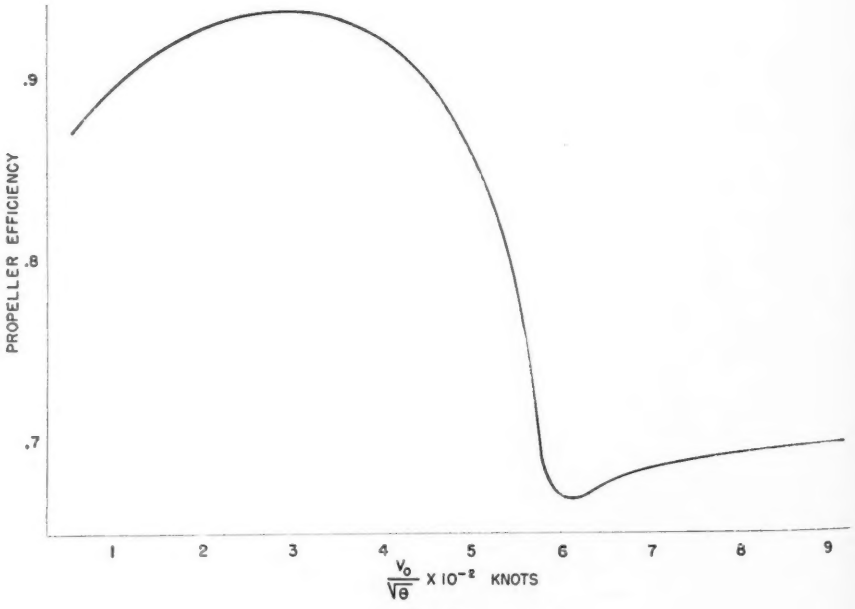


Fig. 30.
Maximum propeller efficiency.

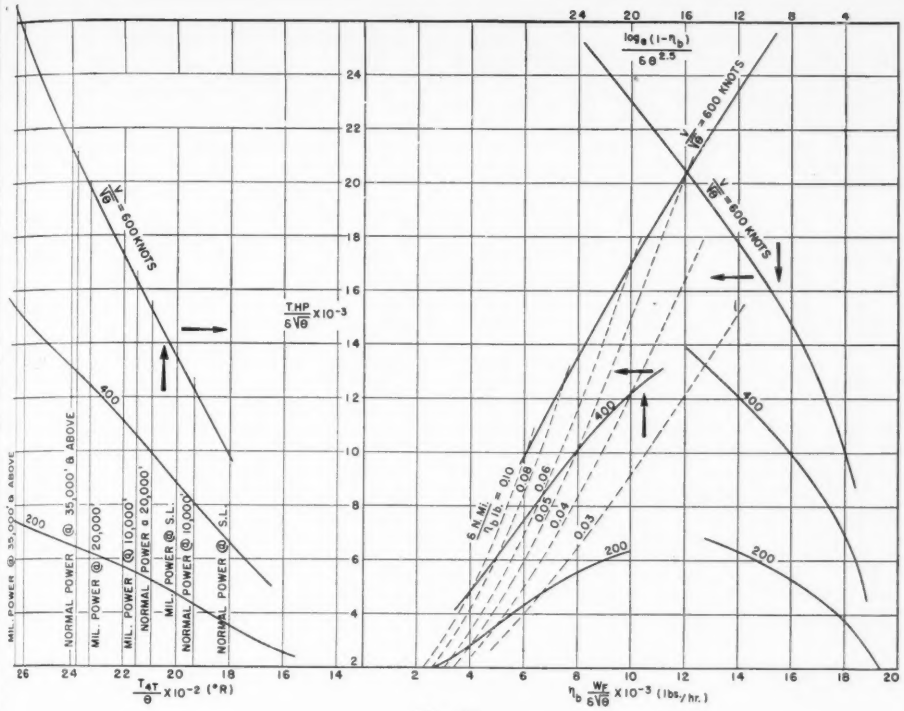


Fig. 31.
Example, turbo-jet.

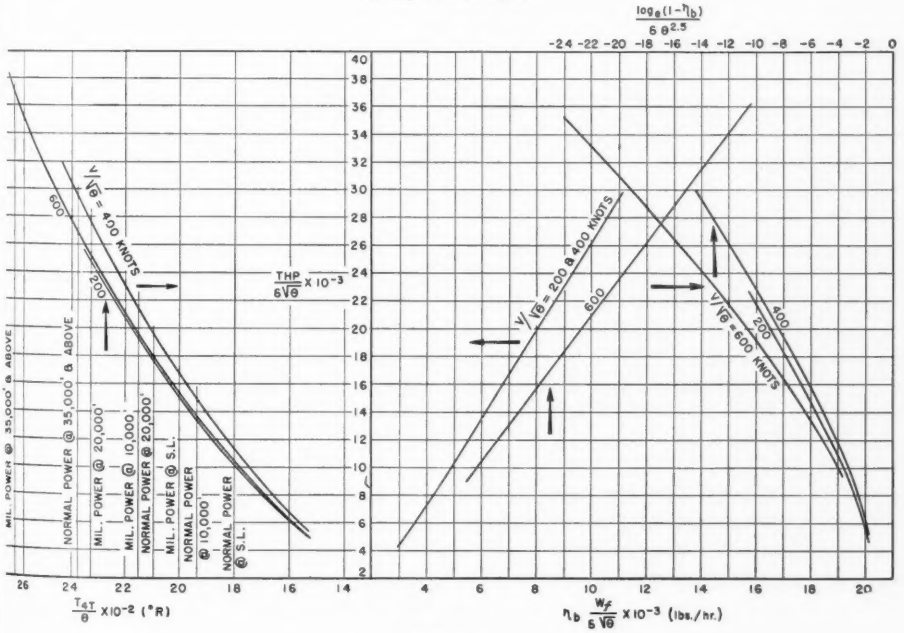


Fig. 32.
Example, turbo-prop.

Therefore

$$\frac{\Delta h_{gcl}}{\theta\tau} = \frac{-1.21 \times 20.3}{1.0} = -24.57 \text{ B.Th.U./lb.}$$

and $\frac{\Delta h_{gc}}{\theta\tau}$ corrected for losses $= 130.11 - 24.57 = 105.54$ B.Th.U./lb.

and $\frac{\text{G.H.P.}}{W_g\,\theta\tau} = 1.415 \times 105.54/1.0147 =$
$= 147.3$ H.P./lb. of gas.

Specific fuel consumption

$$= \frac{0.01472 \times 3600}{147.3 \times 1.0147} = 0.3545 \text{ lb./G.H.P./hr.}$$

The foregoing calculation determines the generator performance at the design point. For other operational conditions a table similar to Table I is filled in.

When estimating the combustion efficiency the additional columns in Table II are required.

Assume $\alpha = -19.95$
$\zeta = 1.5$

Calculate $\eta_c = \frac{1}{e^{14.6 \times 0.016625}} = 0.781$

From Column (19) (Table II) the combustion efficiency under static conditions at sea level may be computed.

The complete example of the turbo-jet generator as computed allows curves similar to Figs. 15, 16, 17 and 28 to be constructed.

If this calculation had been made for a turbo-propeller engine, additional steps would have been required. A value of β, the ratio between the turbine and total generator enthalpies would have been specified or assumed and the increased entropy through the machine determined before computing the generator power. Then, this power would have been divided between the shaft and the exhaust jet.

The procedure is outlined in the following example.

Assumptions

$\Delta h_t/(\theta\tau) = 218$ B.Th.U./lb., $\eta_{lg} = 0.98$

Analysis

$$\Delta S_t = 0.2779\left(1 - \frac{1}{0.93}\right) \times \times \log_e\left(1 - \frac{218}{519.9}\right)$$
$$= 0.00132 \text{ B.Th.U./lb.°R.}$$

$C_{pg} = 0.2779$ at fuel air ratio of 0.01472 and mean temp.

and $\Delta S_T = 0.016625 + 0.01132 + 0.001034$
$= 0.02898$ B.Th.U./lb.°R.

Table I.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
% of Des. $\frac{W_f}{W_a\theta T}$	% of Des. $\frac{GHP}{W_a\theta T}$	% of Des. $\frac{\Delta h_c}{h_2}$	$\eta_b \frac{W_f}{W_g\theta T}$	$\frac{GHP}{W_g\theta T}$	$\frac{h_3}{\theta T}$	$\frac{\Delta h_b}{\theta T}$	$\frac{h_4}{\theta T}$	$\frac{T_{4T}}{\theta T}$	% of Des. $\frac{T_{4T}}{\theta T}$	% of Des. $\frac{N}{\sqrt{\theta T}}$	% of Des. $\frac{W_g\sqrt{\theta T}}{\delta p_2/p_{a_0}}$	$\frac{W_g\sqrt{\theta T}}{\delta p_2/p_{a_0}}$	$\frac{\Delta h_{gc}}{\theta T}$	$\frac{\Delta h_b}{\theta T} - \frac{\Delta h_{gc}}{\theta T}$	$\frac{\Delta GHP}{W_g\theta} \frac{P_0}{100\sqrt{\theta}}$
60	40	78.4	.00884	58.9	222.0	162.6	384.6	1540	76.6	87.6	83.3	101.4	42.3	120.3	1.571
70	55	83.6	.0103	80.0	228.5	189.6	418.1	1655	82.3	90.8	87.2	106.0	57.1	132.5	1.645
80	69.5	89.0	.01179	102.9	235.0	217.0	452.0	1780	88.6	94.2	91.7	111.5	73.8	143.2	1.705
90	85	94.5	.01325	125.2	242.0	244.0	486.0	1900	94.5	97.3	95.9	116.6	89.8	154.2	1.768
100	100	100.0	.01472	147.3	248.9	271.0	519.9	2010	100	100	100	121.7	105.7	165.3	1.832
110	115.3	105.0	.0162	170.0	255.0	298.0	553.0	2120	105.5	102.7	103.8	126.2	122.0	176.0	1.895
120	130.6	109.0	.01769	192.5	260.0	325.0	585.0	2220	110.5	105.1	106.7	130.0	138.1	186.9	1.954

Column 1—Chosen.
„ 2—From Fig. 19.
„ 3—From Fig. 22 at $\left(\frac{\Delta h_c}{h_2}\right)_{des} = 1.00$.
„ 4—Col. (1) × 0.01472.
„ 5—Col. (2) × 147.3.
„ 6—$124.46\left[1 + \frac{\text{Col. (3)}}{100}\right]$
„ 7—From equation (31).
„ 8—Col. (6) + Col. (7).
„ 9—From Fig. 21.
„ 10—Col. (9)/2010°R.
„ 11—√Col. (10).
„ 12—From Fig. 20 at $\left(\frac{\Delta h_c}{h_2}\right)_{des} = 1.00$.
„ 13—[120.0 × 1.0147] × Col.(12).
„ 14—$\frac{\text{Col. (5)}}{1.415} \times [1 + \text{Col. (4)}]$
„ 15—Col. (7) − Col. (14).
„ 16—From Fig. 12 multiplied by 1.415/[1 + Col. (4)].

Table II.

1	17	18	19
% of Des. $\frac{W_f}{W_g \theta T}$	$\left(1+\frac{\Delta h_c}{h_2}\right)^{4.5}$	$\left(\frac{W_f}{W_g \theta T}\right)^3$	X
60	13.5	.0083	- 1.745
70	15.4	.00102	- 2.45
80	17.5	.00129	- 3.08
90	19.95	.00151	- 4.70
100	22.65	.0018	- 6.36
110	25.2	.00202	- 7.83
120	27.6	.00219	- 9.41

Column 17 – $\left[1+\frac{\text{Col. (3)}}{100}\right]^{4.5}$

Column 18 – [Col. (4)]$^{1.5}$.
$\theta\tau$ and η_b assumed unity in Col. (4).
Column 19—From Definition of X.
$x = -19.95 \times 0.781 \times$ Col. (17) $\times$ Col. (18).

Then from Fig. 14.

$$[V_h/(100\sqrt{\theta})]^2 = -24.8$$

$$\Delta h_{gcl}/(\theta\tau) = \frac{-1.21 \times 24.8}{1.00}$$

$$= -30 \text{ B.Th.U./lb.}$$

$$\Delta h_{gc}/(\theta\tau) \text{ corrected} = 130.11 - 30$$

$$= 100.11 \text{ B.Th.U./lb.}$$

and

$$\frac{\text{G.H.P.}}{W_g \theta\tau} = 1.415 \times 100.11/1.0147$$

$$= 139.9 \text{ H.P./lb. of gas}$$

$$\frac{\Delta h_{gs}}{\theta\tau} = 218 - 124.46 \times 1$$

$$= 93.5 \text{ B.Th.U./lb.}$$

$$\frac{\text{S.H.P}}{W_g \theta\tau} = 0.98 \times 93.5 \times 1.415/1.0147$$

$$= 127.5 \text{ H.P./lb. of gas in shaft}$$

$$\frac{\text{Jet H.P.}}{W_g \theta\tau} = 139.9 - \frac{127.5}{0.98} = 9.9 \text{ H.P./lb. of gas in jet}$$

$$\beta = \frac{127.5}{0.98 \times 139.9} = 0.931.$$

Additional tabular columns will be required, as shown in Table III.

A number of assumptions has been made in this Section that may be open to some debate. For example, the assumption of a programme control which relates the r.p.m. to T_{4T}. The test data as compared to the computed curves on Figs. 26 and 27 is a partial justification for this assumption. Other tests during which the nozzle area for a turbo-jet was varied during static tests gave a very similar agreement between the computed values and the envelope curve for all nozzle areas. Furthermore, many complete engine specifications have been reduced to a single generator curve by this same assumption with excellent results.

It is believed that satisfactory estimates can be obtained by the use of the system proposed if the polytropic efficiencies of the compressor and turbine are known. At least, the estimates will be of sufficient accuracy for preliminary design purposes. It is not intended that the procedures outlined will solve the problems of the engine designer but rather that the aircraft engineer will be able to make good estimates for any new power plant that may appear desirable from his viewpoint and thus assist his co-worker in the power plant field in decisions for future development.

The combustion efficiency data is admittedly very empirical and somewhat meagre but, it is believed, the use of the form of the equations given will probably fit the test results of any chamber that may be designed. The values for the empirical exponents α and ζ will naturally show considerable variation.

Table III.

1	20	21	22
% of Des. $\frac{W_f}{W_g \theta T}$	$\frac{\text{GHP}}{W_g \theta T}$	$\frac{\text{S.HP}}{W_g \theta T}$	$\frac{\text{Jet HP}}{W_g \theta T}$
60	56.0	51.1	3.87
70	76.0	69.4	5.24
80	97.7	89.2	6.74
90	119.0	108.5	8.21
100	139.9	127.5	9.90
110	161.5	147.2	11.15
120	182.9	166.8	12.6

Column 20—Col. (2) $\times$ 139.9.

„ 21—$\beta \times$ Col. (20) $\times \eta_g = 0.931 \times$ Col. (20) $\times$ 0.98.

„ 22—$(1-\beta) \times$ Col. (20) $= 0.69 \times$ Col. (20).

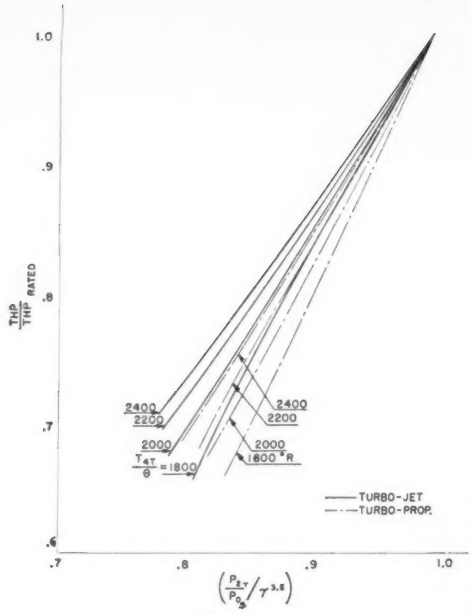


Fig. 33.
Power loss due to inlet duct pressure drop both turbo-jet and turbo-prop.

5. THE PROPULSIVE SYSTEM

Before the Generator Power obtained by the methods described in the previous Section can be plotted on the logarithmic Thrust Horsepower Graph, a propulsive efficiency must be introduced. Usual definitions for jet efficiency or propeller efficiency are not satisfactory for the purpose and, in fact, the two usual definitions for these quantities are quite inconsistent between themselves. The propulsive efficiency for use in this paper will be defined as

$$\eta = \frac{\text{T.H.P.}_{\text{avail}}}{\text{G.H.P.}} \quad . \quad . \quad (40)$$

Therefore, a simple multiplication of the previously determined generator power by this efficiency gives the required thrust power available for propelling the aeroplane.

For a turbo-jet, Equation (40) may be expanded as follows:

$$\text{T.H.P.} = \frac{u_0}{550g}[(W_a + W_f)\,u_j - W_a\,u_0]$$

u_j = jet velocity in ft./sec.
u_0 = flight speed in ft./sec.
$u_j = [2g\,J\,\Delta h_g\,\eta_n/(1+W_f/W_a)]^{\frac{1}{2}}$
J = mechanical equivalent of heat
Δh_g = total generator useful enthalpy—B.Th.U./lb.
η_n = jet nozzle efficiency.

$$\text{But } \Delta h_g = \frac{\text{G.H.P.}}{W_g} \times \frac{550}{J} \times \left(1 + \frac{W_f}{W_a}\right)$$

Therefore

$$u_j = [1100g\,\eta_n\,\text{G.H.P.}/(W_g)]^{\frac{1}{2}}$$

Then $\eta_{jet} =$

$$\frac{\sqrt{\left[\frac{2}{550g}\eta_n \frac{\text{G.H.P.}}{W_g} u_0^2\right]} - \frac{u_0^2}{550g}\Big/\left(1+\frac{W_f}{W_a}\right)}{\frac{\text{G.H.P.}}{W_g}}$$

Let $P_g = \text{G.H.P.}/(W_g\,\theta)$

and $P_a = (u_0^2/\theta)/(1100g) = V_0^2/(386g\,\theta)$ } power in air stream per lb.

Then

$$\eta_{jet} = 2\sqrt{(\eta\,P_a/P_g)} - 2(P_a/P_g)/\,(1+W_f/W_a) \quad (41)$$

Equation (41) is plotted on Fig. 29 as η_{jet} against $V_0^2/(\text{G.H.P.}/W_g)$ for η_n equal to 0.95. The term $(1+W_f/W_a)$ is given as a parameter on these curves. It is interesting to note that jet efficiency defined in this manner has a maximum value of $\eta_n/2$, when W_f/W_a equals zero.

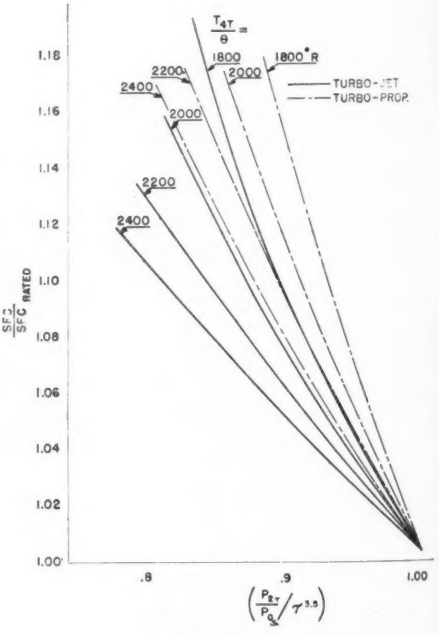


Fig. 34.
Increase in specific fuel consumption due to inlet duct pressure drop both turbo-jet and turbo-prop.

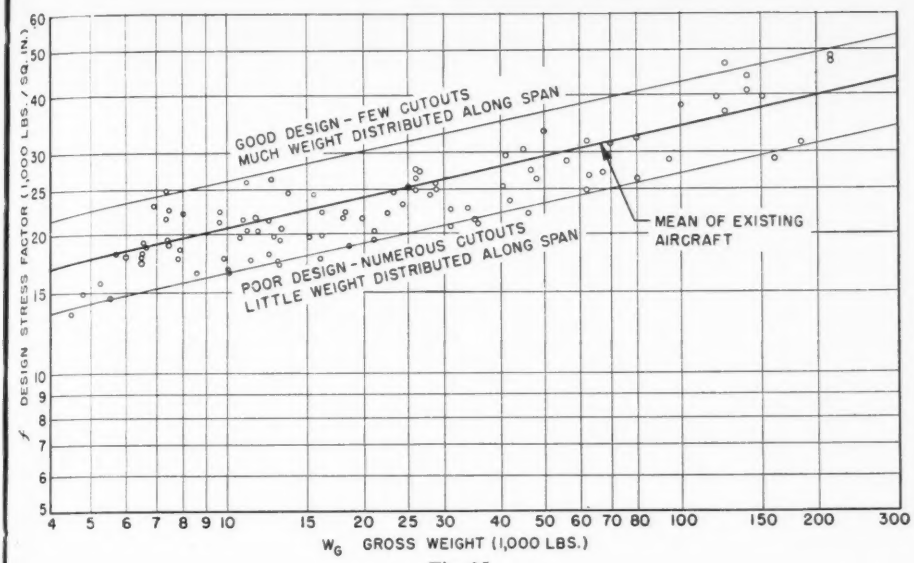

GOOD DESIGN - FEW CUTOUTS
MUCH WEIGHT DISTRIBUTED ALONG SPAN
MEAN OF EXISTING AIRCRAFT
POOR DESIGN - NUMEROUS CUTOUTS
LITTLE WEIGHT DISTRIBUTED ALONG SPAN
f DESIGN STRESS FACTOR (1,000 LBS. / SQ. IN.)
W_G GROSS WEIGHT (1,000 LBS.)

Fig. 35.
Estimation of wing weight.

zero. This fact also can be shown by maximisation of (41). This equation allows the specific generator power to be converted to turbo-jet thrust horsepower per lb. of gas. This procedure may be outlined as follows:

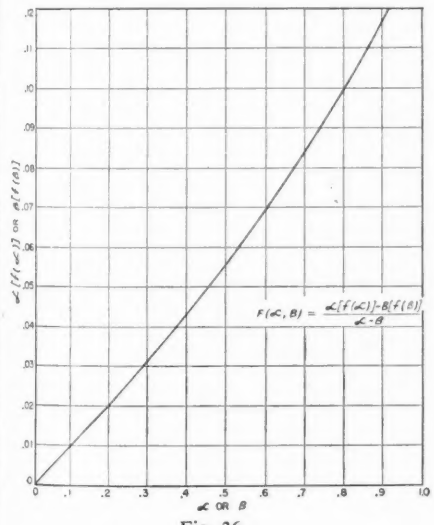


Fig. 36.
Wing weight function $F(\alpha, \beta)$.

1. At a series of values of $\frac{W_f}{W_a \theta \tau}$ determine $\frac{\text{G.H.P.}}{W_g \theta \tau}$ and $\frac{\Delta\text{G.H.P.}}{W_g \theta} \Big/ \frac{V_D^2}{100\sqrt{\theta}}$ from the graphs similar to Figs. 15 and 17.
2. At a series of velocities compute τ and multiply the specific generator powers and fuel air ratios by these values to obtain $\text{G.H.P.}/(W_g \theta)$ and $W_f/(W_a \theta)$.
3. At these same series of velocities calculate $[V_0/(100\sqrt{\theta})]^2$ and multiply the values from Fig. 17 by these factors obtaining $\Delta\,\text{G.H.P.}/(W_a \theta)$ due to flight speed.
4. Add values from (3) to power values from (2) to obtain total specific power *versus* fuel air ratio curves at a series of air speeds.
5. From Fig. 28 determine the values of η_{jet} corresponding to the power and speed values of (4).
6. Convert power values of (4) to thrust horsepower by multiplying by the efficiencies from (5).

The values found cannot be used with the aeroplane performance graphs until multiplied by the mass flow of gas. Since tail pipe burning for jet augmentation is being employed in the majority of current turbo-

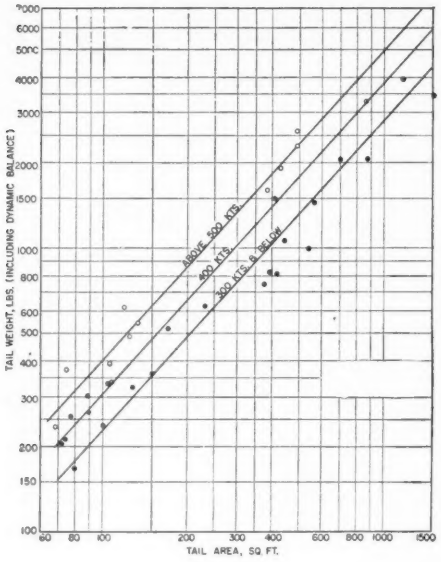


Fig. 37.
Tail weight.

jets in the United States, variable area nozzles are being specified. This fact eliminates the necessity for balancing the laws of conservation of mass and conservation of energy at the nozzle and permits the direct multiplication of the specific power and the fuel air ratio by the mass flow of gas from Fig. 16, at a series of peak cycle temperatures and velocities. This process is done in the following steps:

1. Compute values of p_{2T}/p_{0s} at the same series of air speeds used above. (This ratio equals $\tau^{3.5}$ with no duct losses.)
2. Multiply values of $\dfrac{W_g\sqrt{(\theta\tau)}}{\delta\, p_{2T}/p_{0s}}$ by $(p_{2T}/p_{0s})/\tau^{\frac{1}{2}}$ to remove effects of velocity. (This factor equals τ^3 with no duct losses.)
3. Multiply T.H.P./$(W_g\theta)$ by values from (2) above to obtain T.H.P./$(\delta\sqrt{\theta})$ which can now be plotted on the Thrust Horsepower Graph.
4. Multiply values of $W_f/(W_g\theta)$ by the values of $(W_g/\delta)\sqrt{\theta}$ from (2) above and then multiply by 3,600 to obtain $W_f/(\delta\sqrt{\theta})$ in lb./hr.
5. Divide the series of chosen speeds in knots, $V_0/\sqrt{\theta}$, by (4) to obtain values of $\delta \times$ n.mi./lb. cross-plotting the results to obtain even values for the Thrust Horsepower Graph.

The extension of the example from the previous Section will clarify this procedure.

The turbo-prop engine presents a more difficult problem than the turbo-jet since the power is divided between the propeller and exhaust nozzle and a simple relationship for efficiency cannot be written as readily. There seem to be too many variables to handle in a simple manner. It is realised that an expression can be written for thrust horsepower with a number of variables taken as constant and by the process of maximisation the best division of generator energy between the propeller and exhaust nozzle obtained for any one condition. Such a division of power does not necessarily hold for other speeds or altitudes but may, in fact, impose penalties. The Research Division prefers to follow a process based upon the following assumptions:

(*a*) A variable area exhaust nozzle will be used so as to permit tail pipe burning for high speed operation, if desired.

(*b*) The expansion through the turbines will drop the pressure to a value above ambient in the static condition, that is, some static thrust will be produced by the jet pipe.

(*c*) The increase in enthalpy due to ram will be absorbed entirely by expansion

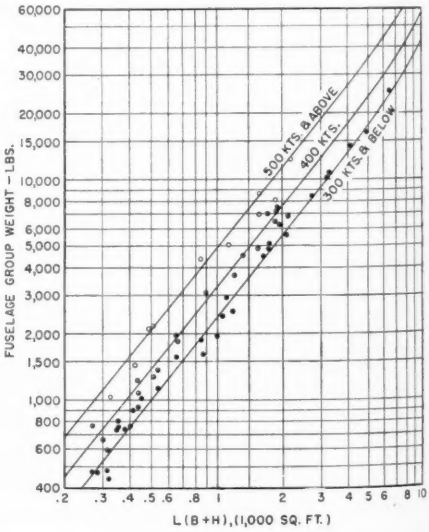


Fig. 38.
Fuselage weight.

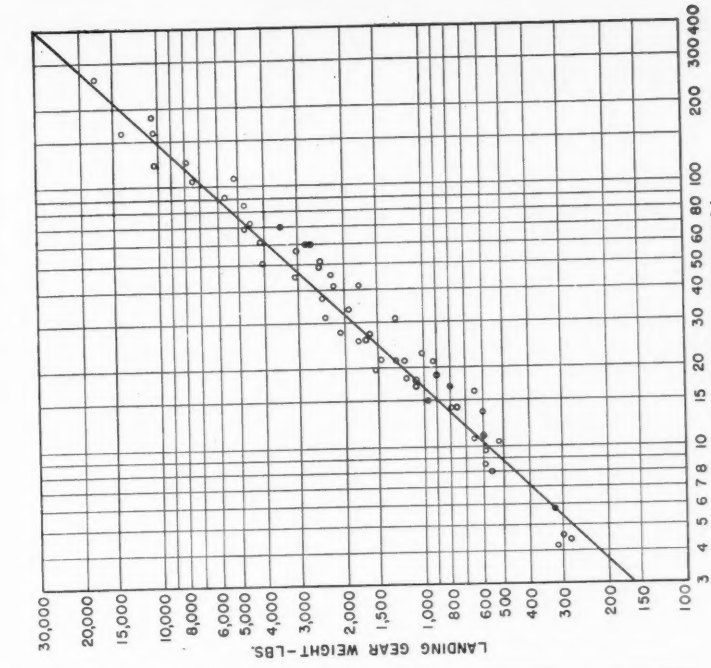


Fig. 40.
Landing gear weight.

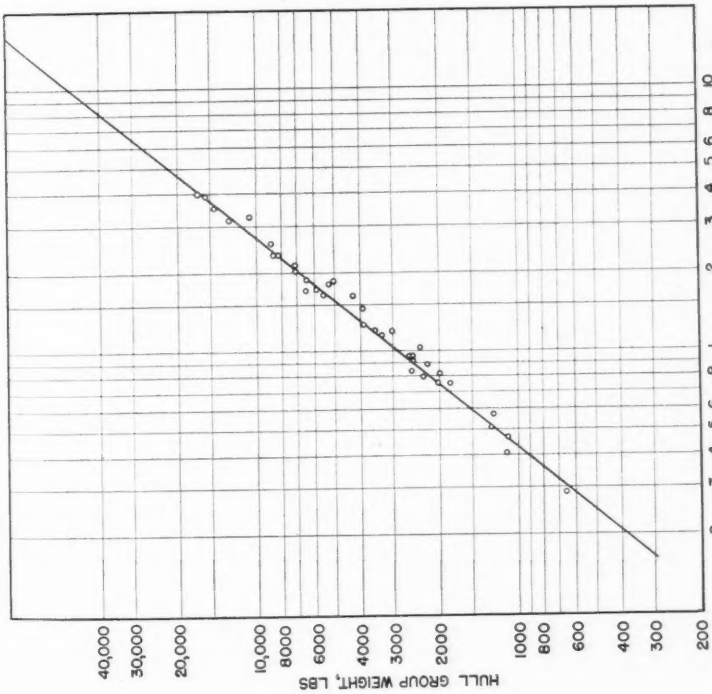


Fig. 39.
Hull group weights.

through the jet, that is, the enthalpy being absorbed by the shaft, $\Delta h_{gs}/(\theta\tau)$, remains a constant function of the fuel air ratio, and is determined by the value β defined in the previous Section.

From these assumptions it is evident that the weight flow of gas is a function of the r.p.m. alone and is unaffected by the nozzle area and that the turbine efficiency with ram will remain the same as used in the determination of the static generator curve. Therefore, as the air speed is increased, a greater proportion of the total enthalpy is converted to jet thrust horsepower, thereby tending to decrease the effect of possible propeller losses at high forward speed.

Following from these assumptions, the generator power curve is divided into two portions, one representing shaft power and the other jet power. The term β was defined in the last Section as the ratio between the enthalpy removed by the shaft and the total available under static conditions.

The Research Division normally assumes that the ratio between the power in the jet, under static conditions, is about 5 per cent. of the total available, unless tail pipe burning is to be employed. In that case, a series of assumptions is made and the best division for some pertinent condition determined. In general, it appears that tail pipe burning will dictate a higher percentage of power for the jet than the 5 per cent. suggested.

The jet propulsive efficiency curve of Fig. 29 and the gas weight flow curve are used to obtain the jet thrust horsepower, the same as for the straight turbo-jet. The shaft power, however, must be multiplied by the propeller propulsive efficiency before adding to the jet power to obtain the total for use on the logarithmic performance graph.

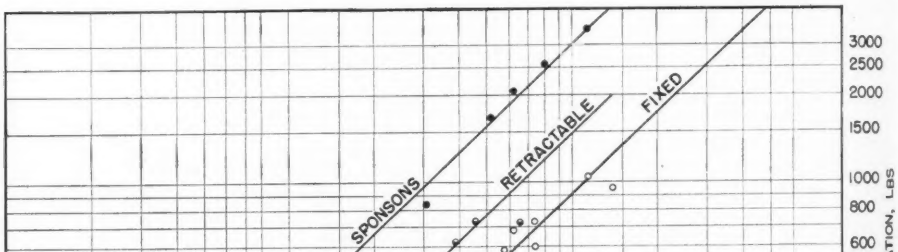


Fig. 41.
Weight of auxiliary flotation systems for flying boats (includes floats, struts and retracting mechanism).

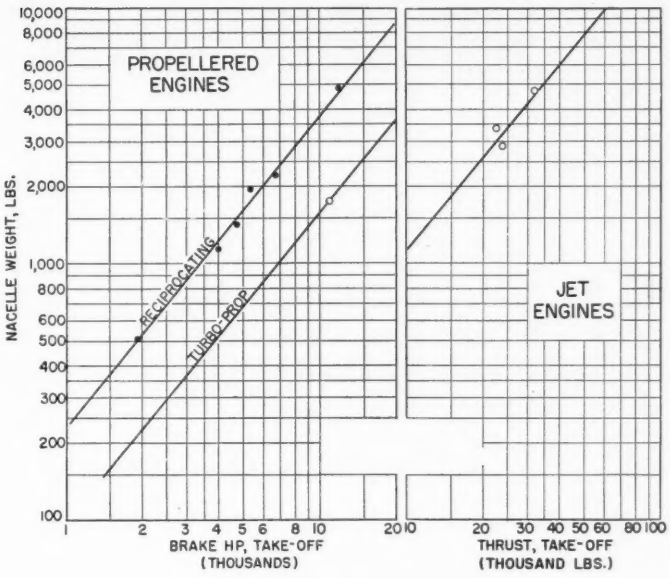


Fig. 42.
Nacelle group.

The gear friction loss has been accounted for in Equation (34) by an efficiency factor, although it is believed that these losses will be a primary function of the r.p.m. and will depend little upon the power. Furthermore, there probably will be no significant decrease in this friction loss with altitude. This is a rather small item and does not seem to warrant the complication of a subtractive loss instead of the simple multiplying factor.

Unfortunately I am unable to discuss current propeller development work and give specific data at high forward speeds. However, a calculated curve for maximum efficiency for a six-blade contra-rotating design can be shown, as on Fig. 30. The values given are based upon an analysis of tests which were made a number of years ago on quite thick blade elements and probably represent the characteristics of a propeller using N.A.C.A. 16 series sections 8 per cent. thick at the $\frac{3}{4}$ radius. The spinner is 25 per cent of the propeller diameter in order to cover up the thick drag producing sections at the root. Tests have indicated that by far the greatest losses at high speed are caused by poorly faired roots. Thin propeller tips may operate supersonically without catastrophic losses in efficiency but thick, poorly formed shanks may decrease the efficiency to very unfavourable values. Both wind tunnel and flight tests have demonstrated the correctness of these statements.

The following examples illustrate the procedure used in calculating the thrust horsepower for both the turbo-jet and the turbo-propeller engine whose generator performances were estimated in the last Section.

Turbo-jet

Table IV follows directly from the previous calculation of the generator performance of a turbo-jet. The calculation for $V_0/\sqrt{\theta}$ equal to 200 knots is shown. The analysis for other velocities is carried out in a similar manner

$$V_0/\sqrt{\theta}=200 \text{ knots}; [V_0^2/(100\sqrt{\theta})]=4.0$$
$$\tau = 1.01825$$
$$\tau^3=1.0557=p_{2T}/(p_{0s}\sqrt{\tau}),\ \tau^6=1.1145.$$

The data from this calculation with data obtained by extension of the analysis to 400 and 600 knots is given on Fig. 31, in a manner convenient for transfer to the logarithmic thrust horsepower graph. Even values

Table IV.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
$\eta_b \frac{W_f}{W_g \theta T}$	$\frac{GHP}{W_g \theta T}$	$\frac{W_g \sqrt{\theta T}}{\delta p_2/p_0}$	$\frac{\Delta GHP}{W_g \theta} \Big/ \left(\frac{V_0}{100\sqrt{\theta}}\right)^2$	$\frac{T_{4T}}{\theta T}$	X	$XT^{4.5+\zeta}$ equals $\frac{\log_e(1-\eta_b)}{\delta \theta^{1+\zeta}}$	$\frac{GHP}{W_g \theta}$	$\frac{W_g \sqrt{\theta}}{\delta}$	$\frac{\Delta GHP}{W_g \theta}$	$\frac{GHP_T}{W_g \theta}$	$\frac{V^2}{GHP_T \times 10^{-3}} \Big/ \frac{}{W_g \theta}$	η_j	$\frac{THP}{\delta \sqrt{\theta}}$	$\frac{\eta_b W_f}{\delta \sqrt{\theta}}$ lb/hr	$\frac{T_{4T}}{\theta}$
.00884	58.9	101.4	1.571	1540	-1.745	-1.945	60.0	107.0	6.3	66.3	.603	.340	2415	3470	1569
.0103	80.0	106.0	1.645	1655	-2.45	-2.73	81.5	112.0	6.6	88.1	.454	.300	2960	4232	1685
.01179	102.9	111.5	1.706	1780	-3.08	-3.43	104.7	117.7	6.8	111.5	.359	.276	3612	5095	1811
.01325	125.2	116.6	1.768	1900	-4.70	-5.24	127.5	123.1	7.1	134.6	.297	.258	4280	5990	1935
.01472	147.3	121.7	1.832	2010	-6.36	-7.09	150.0	128.5	7.3	157.3	.254	.246	4970	6940	2047
.0162	170.0	126.2	1.895	2120	-7.83	-8.72	173.0	133.3	7.6	180.6	.221	.226	5440	7920	2160
.01769	192.5	130.	1.954	2220	-9.41	-10.49	196.0	137.2	7.8	203.8	.196	.214	5980	8910	2260

Columns 1, 2, 3, 4 and 5 are Columns (4), (5), (13), (16) and (9) of generator performance.
Column 6—Col. (19) of burner performance.
„ 7—Col. (5) $\times \tau^{4.5} + \zeta$ = Col. (6) $\times \tau^6$.
„ 8—$\tau \times$ Col. (2).
„ 9—$\tau^3 \times$ Col. (3).
„ 10—$[V_0/(100\sqrt{\theta})]^2 \times$ Col. (4).
Column 11—Col. (8) $\times$ Col. (10).
„ 12—$(V/\sqrt{\theta})^2$/Col. (11).
„ 13—From Fig. 29.
„ 14—Col. (13) $\times$ Col. (11) $\times$ Col. (9).
„ 15—Col. (1) $\times$ Col. (9) $\times \tau \times 3600$.
„ 16—Col. (5) $\times \tau$

for the mileage ($\delta \times$ n. mi./lb.) are assumed and the fuel consumption computed at the series of speeds given, since

$$\frac{W_f}{\delta \sqrt{\theta}} = \frac{V_0/\sqrt{\theta}}{\delta \times \text{n.mi./lb.}} \quad . \quad (42)$$

The points on the T.H.P./($\delta\sqrt{\theta}$) curves at each constant mileage chosen are thus obtained.

The combustion efficiency data are not employed in plotting the logarithmic graph but is used after an altitude is chosen for a cruising operation to correct the range computed by the method outlined in the first Section.

Turbo-prop

The calculation below and in Table V follows the outline suggested for the analysis of a turbo-prop engine. The propeller efficiency is assumed to be constant at all powers at constant air speed following the data shown on Fig. 30 for changes in velocity. Again the analysis for a single speed only is given.

$$\frac{V_0}{\sqrt{\theta}} = 200 \text{ knots}; \left(\frac{V_0}{100\sqrt{\theta}}\right)^2 = 4$$

$$\tau = 1.01825; \eta_{prop} = 0.921 \text{ from Fig. 30}$$

$$\tau^3 = 1.05571$$

The mileage is computed in the same way as for the turbo-jet, although the curves cannot be shown on Fig. 32 due to the coincidence of the 200 and 400 knot thrust horsepower curves. Again the combustion efficiency values are not used until after a cruising altitude has been chosen.

A comment upon Figs. 31 and 32 appears to be indicated. Although the powers are not plotted to the same scale so a direct comparison can be made simply, the selection of a few points shows that the turbo-prop operating at $V_0/\sqrt{\theta}$ equal to 600 knots and military power produces a value for T.H.P./($\delta\sqrt{\theta}$) of 37,000, while the turbo-jet gives only about 27,000. This difference of 27 per cent. warrants further development of the turbo-prop engine and propellers to be employed with it. Both the values are obtained at 35,000 feet.

The foregoing examples were calculated with no inlet duct losses, that is with V_D equal to V_0. If, after an aeroplane layout has been decided upon, it appears that duct losses are probable a correction to the curves of Figs. 31 and 32 will be necessary. After the pressure losses have been estimated, Fig. 18 gives the value of $[V_D/(100\sqrt{\theta})]^2$ at a series of true speeds, $V_0/\sqrt{\theta}$. This value must be used when converting the curve of Fig. 17 to increment in specific power Δ G.H.P./($W_g \theta$). Also the pressure ratio p_{2T}/p_{0s} no longer equals $\tau^{3.5}$, as used in foregoing examples. Thus the mass flow of

Table V.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
$\eta_b \frac{W_f}{W_g \theta T}$	$\frac{SHP}{W_g \theta T}$	$\frac{Jet HP}{W_g \theta T}$	$\frac{W_g\sqrt{\theta T}}{\delta p_2/p_0}$	$\frac{\Delta GHP}{W_g \theta} \frac{V_0}{100\sqrt{\theta}}^2$	$\frac{T_{4T}}{\theta T}$	$\frac{Jet HP}{W_g \theta}$ Static	$\frac{\Delta JHP}{W_g \theta}$	$\frac{Jet HP}{W_g \theta}$ Tot.	$\frac{V_0^2}{JHP/W_g} \times 10^{-3}$	η_{jet}	$\frac{W_g\sqrt{\theta}}{\delta}$	$\frac{THP\ Jet}{\delta\sqrt{\theta}}$	$\frac{THP\ Prop}{\delta\sqrt{\theta}}$	$\frac{THP\ Total}{\delta\sqrt{\theta}}$	$\frac{W_f}{\delta\sqrt{\theta}}\eta_p$ lb/hr	$\frac{T_{4T}}{\theta}$
.00884	51.1	3.87	101.4	1.586	1540	3.94	6.31	10.25	3.9	.474	107.0	520.0	5120	5640	3470	1569
.0103	69.4	5.24	106	1.661	1655	5.34	6.65	11.99	3.34	.480	112.0	644.5	7280	7924	4232	1685
.01179	89.2	6.74	111.5	1.725	1780	6.86	6.90	13.76	2.907	.480	117.7	778.0	9835	10613	5095	1811
.01325	108.5	8.21	116.6	1.794	1900	8.36	7.18	15.54	2.575	.478	123.1	915.0	12520	13435	5990	1935
.01472	127.5	9.90	121.7	1.869	2010	10.08	7.48	17.56	2.279	.473	128.5	1069.0	15350	16419	6940	2047
.0162	147.2	11.15	126.4	1.932	2120	11.35	7.73	19.08	2.098	.468	133.5	1192.0	18410	19602	7920	2160
.01769	166.8	12.6	130.0	2.00	2220	12.82	8.00	20.82	1.92	.464	137.3	1326.0	21450	22776	8910	2260

Columns 1-6—From previous tables of generator performance for turbo-prop.
Column 7—Col. (3) $\times \tau$.
" 8—Col. (5) $\times (V_0/100\sqrt{\theta})^2$ = Col. (5) $\times 4$.
" 9—Col. (8)+Col. (7).
" 10—$200^2 \times 10^{-3} \div$ Col. (9).
" 11—From Fig. 29.
Column 12—Col. (4) $\times \tau^3$.
" 13—Col. (9) $\times$ Col. (11) $\times$ Col. (12).
" 14—0.921 $\times \tau \times$ Col. (2) $\times$ Col. (12).
" 15—Col. (13)+Col. (14).
" 16—$\tau \times$ Col. (1) $\times$ Col. (12) $\times$ 3600.
" 17—$\tau \times$ Col. (6).

gas and fuel are both reduced by any loss in pressure below the full value of $\tau^{3.5}$. Also, the efficiency of the jet for both engine types will be changed due to the reduction in total specific power. For the turbo-jet example, the value of η_j will increase, while for the turbo-prop η_j will either remain substantially constant or increase slightly.

For use with the logarithmic charts of the first Section, it appears that ratios of power and specific fuel consumption between a condition with duct losses and one without will be the most convenient method of handling this problem. When any given engine design as defined by $\Delta h_c/h_2$ has been chosen for analysis the tables may be extended by choosing a few values of the ratio $p_{2T}/(p_{0s}\,\tau^{3.5})$ and recalculating the power and fuel consumption. Additional curves then may be drawn similar to Figs. 31 and 32 for the speed ratios chosen. At constant values of T_{4T}/θ the ratios of power and specific fuel consumption can be found and plotted. Figs. 33 and 34 show such data obtained by an extension of the foregoing examples. No tabular calculation is repeated since it is believed that the method of analysis is sufficiently clear.

Losses occurring in an excessively long tail pipe or due to after-burning flame holders are estimated in a manner similar to the method employed for the inlet duct. In this case, the gas mass flow is unaffected so p_{2T}/p_{0s} equals $\tau^{3.5}$ as in the tables above. Only the specific generator power and the propulsive efficiency are changed. Since the specific fuel consumption is a ratio between the fuel flow and the power, and since both contain a gas mass term in a linear relation, this effect is eliminated when dividing, leaving only the effect of the loss in specific power and the change in propulsive efficiency. (This is exactly the same condition that exists when a pressure loss is experienced in the tail pipe.) Therefore to estimate the loss in power incident to tail pipe pressure drop the reciprocal of the specific fuel consumption ratios may be employed. This eliminates the necessity for a new analysis for such losses.

When computing the losses in a turbo-prop incident to the additional pressure drops, it is convenient to repeat the original computation, revising Column (20) of the generator analysis. The negative increment in specific generator power under the static condition is obtained from Column (19) and the value of $[V_D/(100\sqrt{\theta})]^2$ read from Fig. 18. If the same value for β is employed the analysis proceeds exactly as in the example, that is the increment in power due to velocity is added on to the jet power with no further corrections for duct losses Figs. 33 and 34 give curves representing both engines.

Table VI

Preliminary Weight Table Date

Design No. Engine

MODEL		
1 Wing Group		
2 Basic Wing		
3 Prov. for folding		
4 Spec. Features		
5 Tail Group		
6 Basic Tail		
7 Dyn. Balance		
8 Fuselage or Hull		
9 Alighting Gear Group		
10 Engine Sect.or Nacelle Group		
11 Power Plant Group		
12 Engines (as installed)		
13 Engine Accessories		
14 Power Plant Controls		
15 Propeller		
16 Starting System		
17 Cooling System		
18 Lubricating System		
19 Fuel System		
20 Fixed Equipment Group		
21 Instruments		
22 Surface Controls		
23 Hydraulic System		
24 Electrical System		
25 Communicating		
26 Armament Prov.(incl.armor)		
27 Furnishings		
28 Anti-Icing Equipment		
29 Auxiliary Power Plant		
30 Auxiliary Gear		
31 TOTAL WEIGHT EMPTY		
32 Crew		
33 Passengers		
34 Fuel - Engine		
35 Fuel - Trapped		
36 Fuel - Aux. P.P.		
37 Oil - Engine		
38 Oil - Trapped		
39 Oil - Aux. P.P.		
40 Oil - Supercharger		
41 Oil - Reduction Gear		
42 Baggage or Cargo		
43 Armament		
44 Fixed Guns & Install.		
45 Flexible Guns & Install.		
46 Bombs & Install.		
47 Torpedo Guns & Install.		
48 Equipment		
49 Navigating		
50 Oxygen		
51 Photographic		
52 Pyrotechnics		
53 Miscellaneous		
54 TOTAL USEFUL LOAD		
55 GROSS WEIGHT		

6. THE AEROPLANE WEIGHT ESTIMATE

The previous Sections have employed a theoretical approach to obtain the desired solutions. Although many attempts have been made to devise a rational method for the estimation of aircraft detail weights, it appears that no amount of analysis will replace a great quantity of actual returned weights of aeroplane parts. With such data, a meagre theory may be employed to group the statistical material in a useful manner.

This Section gives curves and data resulting from the analysis of a large number of United States military and commercial aircraft. This information would be of considerably greater value if the aircraft to which the various points apply could be listed. Unfortunately, this cannot be done at this time. However, the general approach to this problem and the curves shown will be of considerable use and other aircraft designers may plot data from their own experience in a similar manner for comparative purposes.

The Research Division employs a table such as Table VI for the listing of all weights. This table is a repetition of the general group weight statements required by the U.S. Navy and Air Force. It forms a simple guide in making a preliminary weight estimate.

WING GROUP

Like many others, the Research Division has derived a formula for the wing weight after experimenting with many different methods of estimation. As is always the case, this formula gives the best results when applied by the engineers who are most familiar with it and who have specific data upon aeroplanes of similar character upon which to base an estimate of the design stress factor. This formula gives the wing weight in the following form:

$$\frac{W_w}{W_g}(\text{straight taper}) = (0.77\, n\, b/f)\,[4.95 + (b/t_r)\,F(\alpha, \beta,)] \quad . \quad (43)$$

W_g = Aircraft gross weight—lb.

W_w = Weight of wing + ailerons + flaps without folding.

n = Ultimate load factor.

b = Span—ft.

f = Design stress factor.

$\alpha = 1 - [(t_t/C_t)/(t_r/C_r)]$

$\beta = 1 - C_t/C_r$

t_r = Wing thickness at root—ft.

t_t = Wing thickness at tip—ft.

C_r = Wing chord at root.

C_t = Wing chord at tip.

$F(\alpha, \beta)$ = Power series expansion of α, β shown on Fig. 36.

$$\frac{W_w}{W_g}(\text{swept}) = (0.809\, n\, b'/f) \times [4.95 + (b'/t_r)\,F(\alpha, \beta,)] \quad . \quad (44)$$

$b' = b/\cos\Lambda$

Λ = Angle of sweep of wing $\frac{1}{4}$ chord.

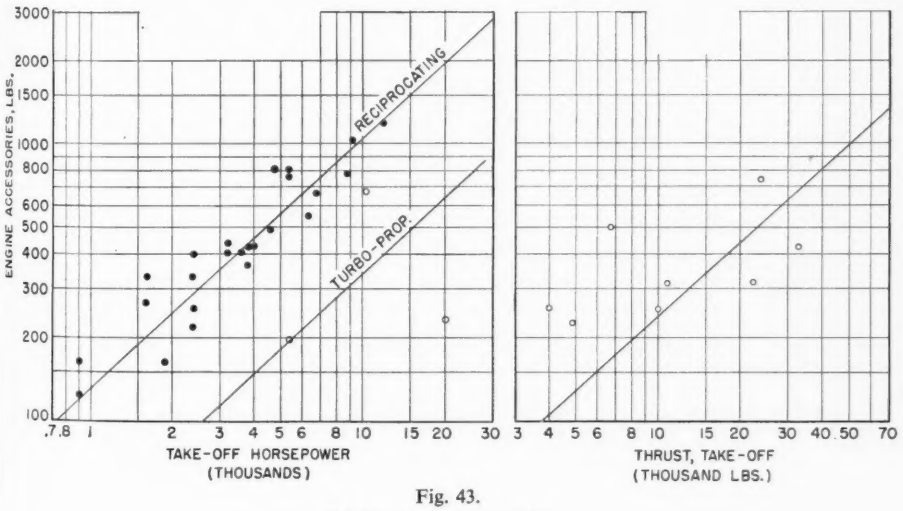


Fig. 43.
Weight, engine accessories.

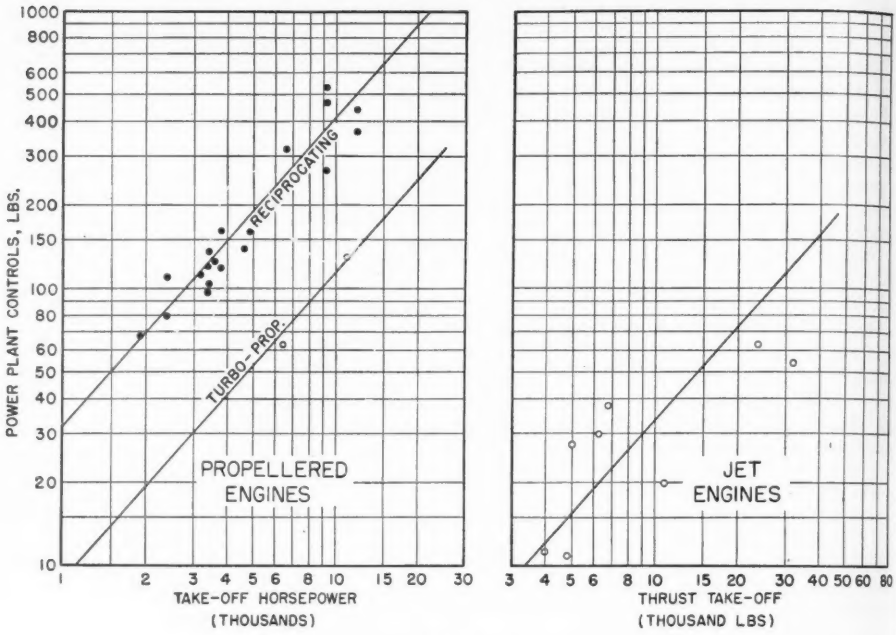


Fig. 44.
Power plant controls.

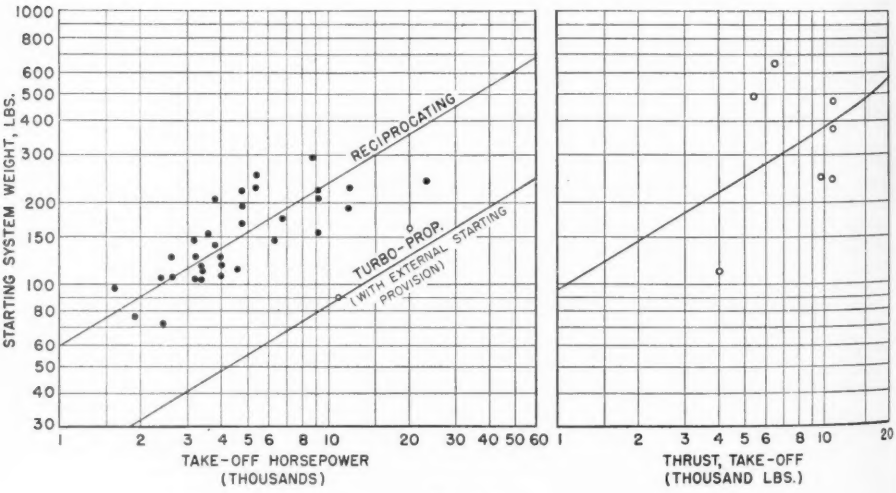


Fig. 45.
Starting systems.

Figure 35 shows graphically the variation of the design stress factor, f, for numerous aeroplanes of various sizes and weights. A mean line has been drawn through the points and also upper and lower bounds indicated. It appears that the greatest number of points group around the mean line within an error of $\pm$ 5 per cent. while the maximum variation may be as much as 20 per cent. for a comparatively small number of points. It is apparent that a comparison between an existing aeroplane and a proposed new design will lead to a closer estimate of the value of f than the direct use of Fig. 35 with no knowledge of the aeroplanes to which any group of points apply. Thus each designer must use data from his own experience when applying the above formulæ. Fig. 35 shows that the points for larger aeroplanes lie close to the upper line. Also, the increase in the allowable stress factor with size is worthy of note. Both these facts seem to be due to a more economical use of material and probably fewer items in the wing structure designed by considerations of practical minimum sizes.

In cases where wing folding is required, the weight as estimated is increased by 5 per cent. This is a mean value and may vary considerably between various folding mechanisms. Again each individual designer should apply factors from his own experience.

Tail Group

The weight of the tail surfaces is plotted against total tail area on Fig. 37. Lines have been drawn through the majority of points which represent aircraft in three design

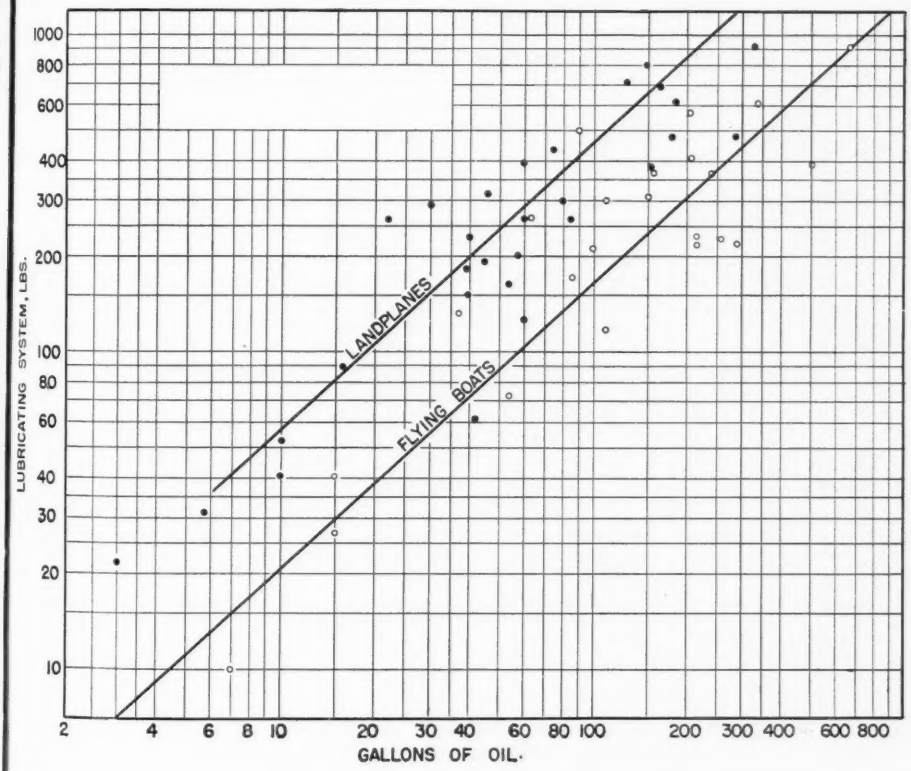


Fig. 46.
Lubricating systems.

speed classes, 300 knots and below, 400 knots, and above 500 knots. As noted on Fig. 37, the weights given include dynamic balance weights.

Fuselage

It is considered that the weight of the fuselage will bear some relation to its total surface area; consequently the graph of Fig. 38 shows fuselage group weight as a function of $L(B+H)$, in square feet

L = Fuselage length—ft.
B = Fuselage width—ft.
H = Fuselage height—ft.

The three lines shown apply to aircraft of various design speeds and were drawn through points representing aircraft of the speeds given.

Hulls

The weights of flying boat hulls are analysed upon the same basis as fuselages; consequently, Fig. 39 shows hull weight as a function of $L(B+H)$ as in the previous case. Since flying boats have been relatively slow no data for other speeds is available.

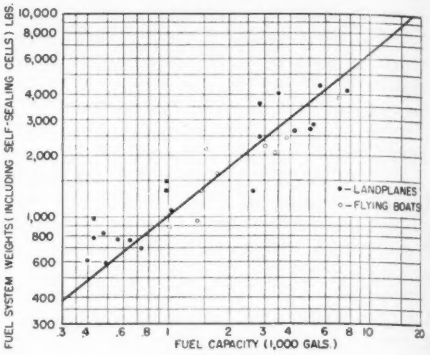


Fig. 47.
Fuel system weights.

Alighting gear group

Figure 40 shows the alighting gear weight plotted against aircraft gross weight.

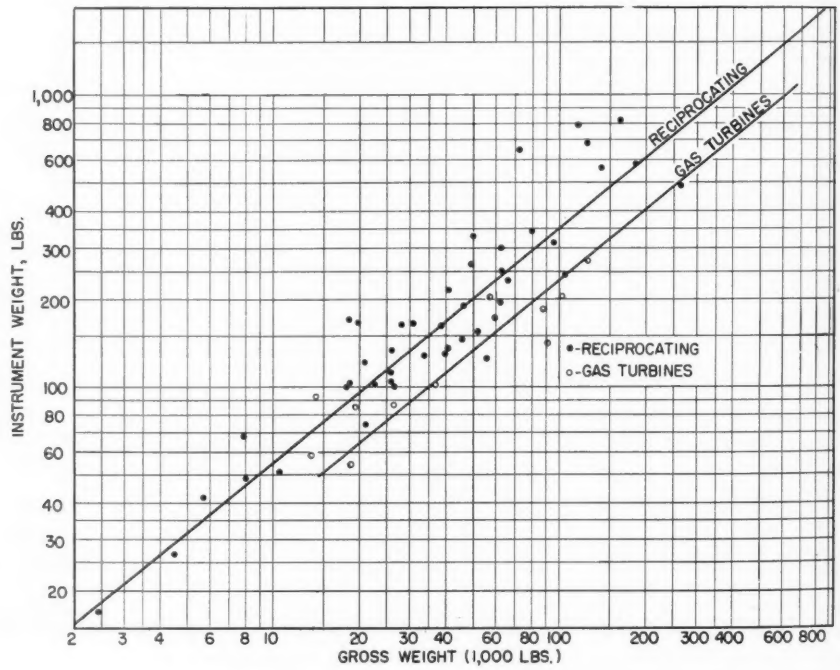


Fig. 48.
Flight and engine instruments.

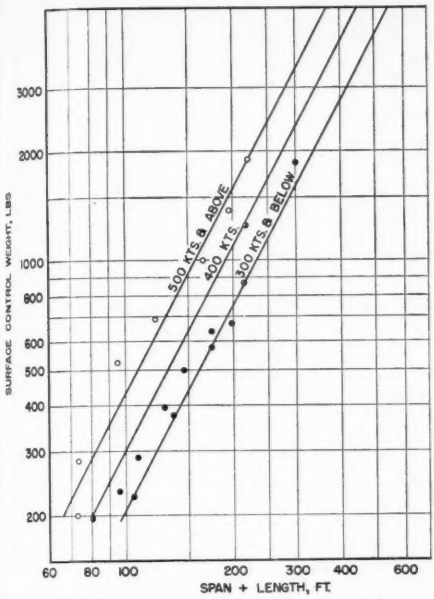


Fig. 49. Weight of surface controls.

Auxiliary flotation systems

Figure 41 gives the weights of various types of auxiliary flotation devices employed on flying boats. Three types are shown, fixed wing tip and retractable floats and sponsons or sea wings.

Engine section or nacelle group

Figure 42 gives data on the weights for the group for three engine types, reciprocating, turbo-prop and jet power plants. The data for the turbo-prop line is meagre as shown and may be considerably in error.

Power plant group

The weight of engines as installed is normally obtained from the manufacturer's specifications. In cases where the Research Division makes an estimate for the performance of a projected power plant, an empirical formula has been devised. This formula gives the weight as a function of the number of stages in the compressor and turbine per unit mass flow of air under the static sea level condition. Too little data has

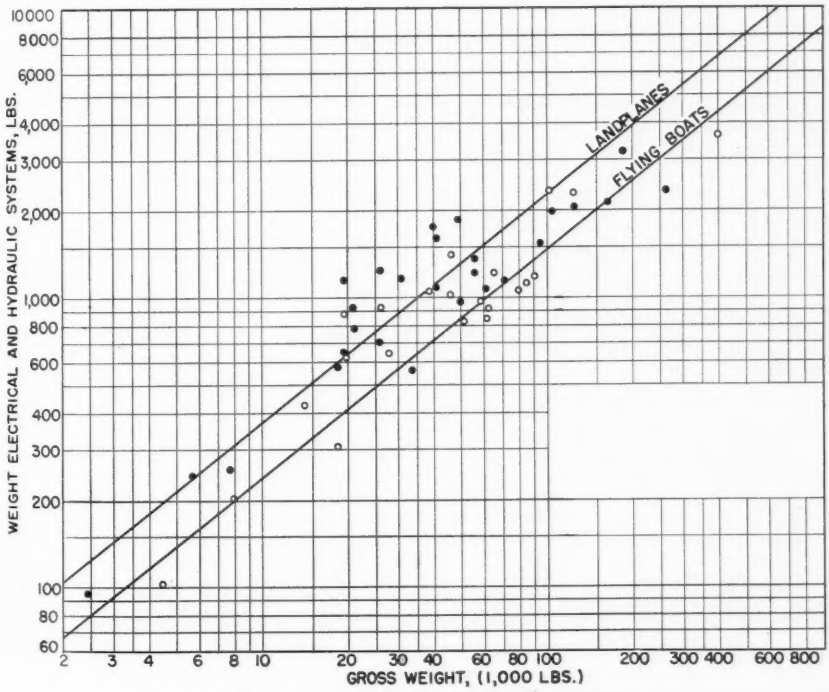


Fig. 50. Electrical and hydraulic systesm.

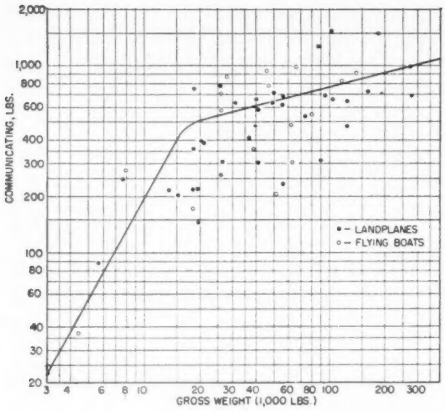


Fig. 51.
Communicating equipment.

been available to check this expression properly so it is not deemed advisable to quote it until more detailed information on a greater number of power plants is available.

Figures 43 to 47 show statistical data for the balance of the power plant group items.

Fixed equipment group

Figures 48 to 55 show data for the various items making up this group.

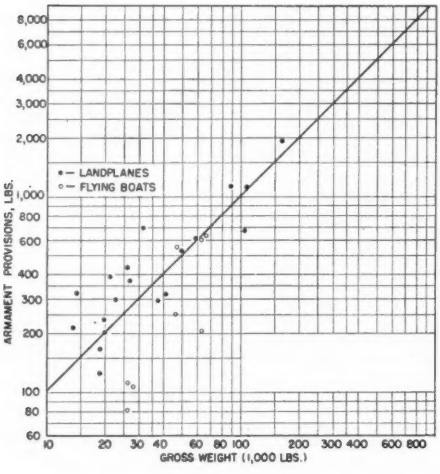


Fig. 52.
Armament provisions less turrets and armour.

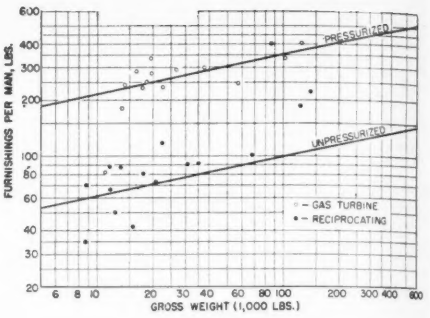


Fig. 53.
Furnishings.

Useful load

It is considered that the useful load will be determined by the specification which will state what any given aeroplane is to carry and how far it is to fly. Consequently, no statistical grouping of data will serve any useful purpose.

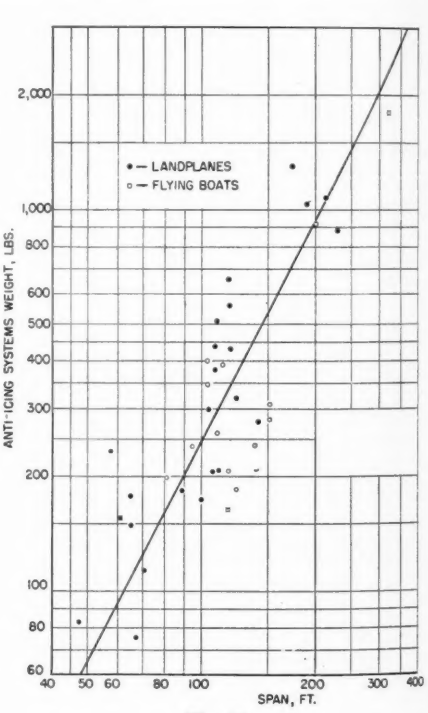


Fig. 54.
Anti-icing systems.

The presentation of the statistical weight data in this Section is the result of the analysis of actual weights for a great number of aircraft, as can be seen by the large number of points. It is realised that these data would be of considerably more value if points shown were identified with the aircraft to which they apply. In many cases that might be done since many obsolete designs are represented but, in other cases, data from newer aircraft have been shown which cannot be identified. It is believed, however, that this is the largest collection of aircraft component weights ever gathered together, and as such it is hoped that it will be of value.

7. CONCLUSION

This paper has covered a considerable number of the problems that are met by the aeroplane designer in the early stages of a preliminary study, but by no means has the complete field been discussed. Aeroplane stability and control might have been included as a major section. The Research Division has developed an empirical-theoretical method of estimating the control and stability characteristics of a proposed design but this work is of little use unless the characteristics of various service aircraft can be adequately referenced. This broad subject should be considered separately.

There are many blanks in the discussion, notably in suggested values for compressor and turbine polytropic efficiencies. The Research Division has endeavoured to obtain these quantities from the various sources and has yet to receive sufficient material for complete analysis. It is probable that these data exist in Great Britain in a manner from which estimates may be made as some function of the heat input (or output) per stage. Although Reference 2 gave some information upon these values, the data is not considered worthy of much consideration.

Another blank is the question of propeller efficiency. Although values are presented on Fig. 30, these data are based upon thick blade elements and consequently show a rather severe drop at high speeds. Development work is proceeding in the United States to confirm or improve these data. This work is being directed along three paths: wind tunnel testing of small model propellers up to a Mach number of .90; tests on individual blade elements upon an operating

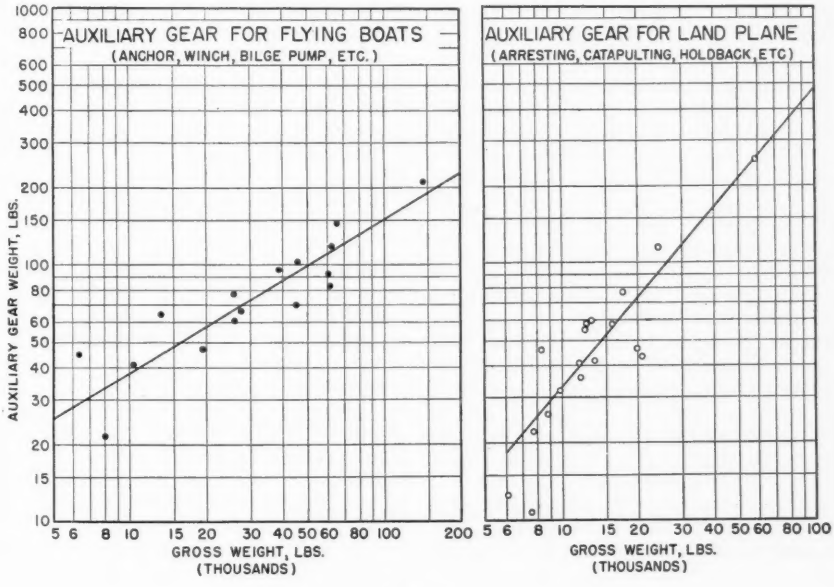


Fig. 55.
Auxiliary gear.

propeller in a wind tunnel to cover the complete range of section Mach numbers likely to be encountered; and flight test employing a jet-driven fighter mounting a turbo-prop in the nose. From the wind tunnel tests to date, both upon models and upon blade elements, it appears that the propeller is still a useful means of driving an aeroplane, even at very high speeds. For low cruising speeds, it is believed, everyone admits the superiority of the propeller. These statements are not to be construed as an attempt to re-sell the use of propellers. The intent is to report facts to an extent consistent with security.

I sincerely trust and hope that the material presented in this paper will be of use to other engineers engaged in the same line of work. Although the Section which discusses the turbine generator is of no direct interest to the engine designer when working out the mechanical design of his component parts, it may be that the methods of presenting data, either from analysis or from tests, may be found useful. The whole method of approach to this problem has done much to clarify the thinking within the Research Division and has made possible many simple papers presented to higher authorities for their better understanding of gas turbine development.

References

1. Driggs. Airplane Performance Calculations by Means of Logarithmic Graphs. *Journal of the Society of Automotive Engineers*, June 1938.
2. Driggs. Preliminary Performance Analysis of Gas Turbine Power Plants. *Journal of the Society of Automotive Engineers*, October 1948.
3. Keenan and Kaye. A Table of Thermodynamic Properties of Air. *Journal of Applied Mechanics*, September 1943.
4. Pinkel and Turner. Thermodynamic Data for the Computation of the Performance of Exhaust Gas Turbines. N.A.C.A. War-time Report A.R.R. No. 4B25, E25, October 1945.

DISCUSSION

S. Scott-Hall (D.G.T.D., Ministry of Supply, *Fellow*): One of the responsibilities of the Ministry of Supply was to do just the work that Mr. Driggs had talked about, the formulation of requirements and specifications for new aircraft and the assessment of projects put forward to those specifications. Hitherto they had not found that mechanical aids were of particular value, because most of their investigations devolved around singular points on the performance carpet and were not a complete analysis of the whole picture. However, one member of the Ministry's staff, Mr. Cohen, used a circular multiple slide rule extensively.

Most of the effort of the Ministry's staff had to be devoted to the estimation of the basic parameters, such as drag rise with Mach number, intake efficiency, and so on; could Mr. Driggs say a little more about his work on that side of the picture? For example, Fig. 5, dealing with drag rise, left them guessing a little; Mr. Driggs had said he assumed that his audience knew all about the factors which fixed critical Mach number in relation to velocity, but that was just the kind of thing which the Ministry staff found most difficult.

He was very interested in equation (44) for wing weight; would Mr. Driggs say a little more about it? It did not appear that any torsional effects were taken into account in that equation, so that it seemed to be somewhat over-simplified.

He questioned the basis on which some of the weights had been analysed. For example, the weight of armament was plotted against the gross weight of aircraft, and this appeared to be an unsuitable basis for such an analysis.

E. J. Richards (Vickers-Armstrongs Ltd., *Assoc. Fellow*): The method would be extremely useful to the research establishments, which were concerned with the trends of future development and examined the effects of every possible variable, such as the drag coefficient, engine power, height, aspect ratio and other things of that sort. But from the point of view of the man in the Industry who was working out the performance of a particular aeroplane it was a little too complex. It seemed rather as though numbers could be put into a machine, the handle turned, and out would come the answer; but it did not indicate how far away they might be from the answer. For example, on an aircraft flying very high, varying results

could be had by slight variations of the method, and even thickness of pencil lines could vary the results to give differences of 500 ft. or so. He did not think Mr. Driggs' method indicated how near they could guarantee to estimate the actual performance and flight handling of an aircraft under given conditions; had the American Industry expressed any views of this sort and was it actually using the method universally?

He had some difficulty in understanding Fig. 8, showing the effect of sweepback on the span efficiency factor; "*e*" which was quoted there was the square root of the reciprocal of what they took as the induced drag factor; but when he compared the effect of sweepback as shown in the figure with the information he had dug out from various sources it looked as though e^2 should have been e. With 40° of sweepback, the factor should go up to an extremely high figure; was his information more optimistic than that of the author?

Could generalisations of that sort really be of value when such things as taper ratios were brought into the matter? A recent lecture given to the Institute of the Aeronautical Sciences examined the effect of this variable and showed the optimum taper ratio for various angles of sweepback to give as nearly as possible elliptical loading and induced drag. Thus with an optimum taper ratio, the induced drag factor would be very nearly unity, even with sweep.

On propeller turbines it was extremely difficult to work back from one condition to another and reduce to standard conditions. In the United States had they reduction methods for propeller turbines which overcame this defect?

A. E. Woodward-Nutt (D.C.A.R.D., Ministry of Supply, *Fellow*): Generalised methods of performance estimation and reduction of design analysis were not new as he was sure Mr. Driggs would admit. In the early 1920's J. D. Coles in Great Britain produced generalised curves for performance estimation, and about 1929, H. L. Stevens and he himself evolved some generalised charts for aircraft performance reduction. Many others had produced special slide rules and other gadgets to speed up that kind of work.

Two points had impressed him about those methods in the past. First, while they were used with enormous enthusiasm by the originators, they were difficult to " get over " to others.

Secondly, none of those generalised methods seemed to have lasted long. Sooner or later it was found that the aircraft designer had been just a bit more clever than had been anticipated and had evolved a tailless aircraft, or one with a delta wing or some other new device, and the aircraft fell outside the range of the generalised method, so that they had to go back to first principles again.

Had Mr. Driggs found that the methods had been accepted with enthusiasm by his own staff and others? Had they been in use for a long period? Had he plans for overcoming that lack of flexibility which had hitherto characterised all methods of that kind and which must to some extent apply to his own method?

Another criticism of generalised methods was lack of accuracy. Had Mr. Driggs made any direct comparisons between treating a given set of data first by straightforward detailed analysis and, secondly, by the use of the methods described in the paper? It would be interesting to have quantitative information of the relative times taken and the relative accuracies of the two methods.

In Fig. 8, span efficiency (*e*) was plotted against aspect ratio. He agreed that that was quite logical, but did not such factors as the kind of junction between wing and body, or the presence of disturbances such as engine nacelles, affect the value (*e*) as much as did aspect ratio?

He was impressed by the veritable constellation of points which Mr. Driggs had got together on the various curves on which the weights of components were plotted; he regretted that it had not been possible to label them with the names of the stars. Could not just a corner of the security veil be lifted so that they knew at least which were the new types of aircraft and which the old, and roughly how old the old ones were? It would be reassuring to know that they had made some progress during the past few years.

Mr. Driggs had cheated a little (although in good company) in using logarithmic scales, since in this way the scatter of the points was sometimes masked. For example, on the curve for landing gear weight (Fig. 40) the ratio between maximum and minimum weights was nearly 2:1 over much of the scale, and the variation of wing weights between good and poor designs was also

substantial (about 1.6:1). It seemed that experienced judgment was needed in using a generalised curve of that nature in any specific case.

J. Cohen (R.D. Projects, Ministry of Supply): A slide rule which he had developed during the past few years made something like the performance estimate which Mr. Driggs had described. It was suggested in the paper that there should be two separate sets of plates, one for performance in shaft power and one for jet thrust. Having visualised that difficulty, he had thought a good deal about it and finally had come to the conclusion that the two could be combined and a slide rule devised which should estimate the performance for a generalised power plant, *i.e.* one which had both shaft power and jet thrust or only one of each.

The generalised equation of performance where there was both shaft power and jet thrust was:

$$(\eta B + Tv)\sqrt{\sigma} = D(v\sqrt{\sigma})^3 + \left(\frac{W}{be}\right)^2 \frac{1}{(v\sqrt{\sigma})} + Wv_c\sqrt{\sigma}$$

where non-compressible flow was assumed, and where for simplicity the units of the variables were chosen such that the numerical constants could be suppressed. As the variables in their customary units were later fed into logarithmic circuits, the numerical constants were accounted for as permanent shifts in the zeros.

Taking the level speed case where $v_c = 0$ he introduced the equation:

$$T_1 = T\left(1 + \frac{\eta B}{Tv}\right)$$

and the parameter k where

$$T_1 = \left(k^2 + \frac{1}{k^2}\right) W (be)^{-1} D^{\frac{1}{2}}$$

and

$$(v\sqrt{\sigma})^2 = k^2 W (be)^{-1} D^{-\frac{1}{2}}$$

On transposing and taking logs, but omitting the word "log":

$$0 = \left(k^2 + \frac{1}{k^2}\right) + W - b - e + \tfrac{1}{2} D - T_1 \quad (1)$$

and $$0 = 2k + W - b - e - \tfrac{1}{2} D - 2v - \sigma \quad (2)$$

Equation (1) was a circuit to which if W, b, e, D and an assumed T_1 were fed on their respective scales, would determine the value of $(k^2 + 1/k^2)$ required to close the circuit. This value gave k which was fed into the circuit of Equation (2) together with W, b, e, D and σ (or height) and by closure determined v. The existence of common elements in circuits (1) and (2), and other circuits to be described, made it possible to superimpose them so that a single setting of those common elements sufficed for all.

In the equation relating T_1 and T the closure of the circuit formed from $\eta B/(Tv)$, where T was assumed, was aligned to an adjacent similar scale increased by unity and was then circuited with T and closed by T_1, which latter was automatically fed back into circuit (1).

It would appear that neither T_1 nor v could be determined, since each depended on an assumed value of the other. The practice however was to feed in an assumed v, determine T_1 and the new v. An adjustment could then be made to the circuits in a matter of seconds until the two values of v coincided.

The cases when either T or B were zero, *i.e.* when the engine delivered only shaft power or only jet thrust could be dealt with simply by locking some of the scales at certain zeros, and bypassing them.

When dealing with the compressibility drag rise region, use was made of an auxiliary scale of speed of sound at height which gave the Mach number of the speed, assuming non-compressible motion. Reference was then made to the aircraft drag rise curve and an exact correction could be determined immediately for the pure jet thrust, or the pure shaft power case; for the generalised power plant the correction might be re-applied once to get a close degree of accuracy.

For climb performance the power required for forward motion could be found as a percentage of total power and thrust available, so that the remaining percentage added to the weight and speed scale would give rate of climb. The optimum speed of climb was found in a manner similar to that for maximum speed, except that in the pure jet thrust case the scale $(k^2 + 1/k^2)$ of circuit (1) was replaced by an adjacent scale $(3k^2 - 1/k^2)$.

Finally, specific range could be determined as for maximum speed, with reference to the engine consumption data.

The foregoing analysis showed that although the basic performance equation contained addition and multiplication signs, it was possible to incorporate all of it in the form of multiplication quantities and adapt

the relationship of the variables to logarithmic circuits.

The equation contained 10 variables. The slide rule as he had finally developed it, contained 9 rotatable concentric dials, some with multiple scales. There was nothing generalised about those; they were all precise and accurate. All that had to be done was to feed in the weight, the span, the height, the drag, the shaft power, the jet thrust, the induced drag factor, and so on, then rotate the dials and out came the answer in less than a minute! It was as simple as that.

Whether or not there was any universal use for such an instrument it was difficult to assess. But it was useful to obtain answers rapidly, and he believed that, particularly for *ad hoc* problems, his performance slide rule and that which Mr. Driggs had produced should be most useful, for performance problems must be dealt with rapidly.

C. Dykes (British Overseas Airways Corporation, *Assoc. Fellow*): He was much impressed by the close similarity between Mr. Driggs' approach and that of an operator. In the paper the problem was defined as being the need for quick, reasonably accurate, and simple means of studying a broad series of aircraft designs, *i.e.* to make a design study before issuing specific requirements for tender. A major operator had to follow precisely the same process.

He would suggest that other aims of the operator were also those of the Bureau of Aeronautics, although they were not specified by Mr. Driggs. They were the need for quick checks of manufacturers' estimates, and the necessity for maintaining intelligence records regarding other aircraft and equipment.

Mr. Driggs was notable in that he had done so much work with a staff of only eight engineers; that betokened constant attention to simplification of methods. It provided a valuable lesson for everyone, and it was one which he had frequently impressed upon his own staff. It was fatally easy to adopt some refinement of method which did not sufficiently improve accuracy, but which greatly increased the work involved.

He presumed that the eight engineers of Mr. Driggs' staff were supported by a small number of computors; his own experience showed that one girl computor to each engineer was necessary.

B.O.A.C. experience of the similar methods they employed had been good but, like Mr. Woodward-Nutt, they had found that considerable experience was necessary in order to obtain sound answers when applying those methods to determining operationally critical items of performance. They also had generalised power-required charts, and they had compiled a small book on specialised methods.

Did Mr. Driggs use the simple methods given in the paper for such items as take-off, both with all engines and with one engine out; *en route* rate of climb with one engine out; landing, both from an obstacle and the actual roll; baulked landing rate of climb; and minimum control and landing speeds? Did Mr. Driggs find, as did B.O.A.C., that it was necessary to go to considerable complexity in determining thrust and drag under those conditions?

For generalised power-required charts, B.O.A.C. used a design with only one overlay. They had found that it did not always provide the most rapid method and that, particularly where performance over a wide range of weights was required, *i.e.* for the long range aircraft or patrol bomber, the family of curves could frequently be drawn quicker by direct calculation. Mr. Driggs' slide rule with three overlays was possibly a useful means of obtaining such curves, and they would certainly try it.

He did not claim to be an expert on engine performance calculations, but felt there were many who would like to take issue with Mr. Driggs in that connection.

Mr. Driggs' treatment of weight data was exactly that adopted by the B.O.A.C., namely, a statistical summary based on experience; they had recently made studies on those lines, and he hoped they would be able to publish the results shortly.

Surprisingly, they had found that a simple formula for wing weight, based only on the span, gave a mean deviation no greater than those of other formulæ with three, or in some cases no less than ten, variables. The moral was obvious, that simplicity usually paid. The reason might be that transport aircraft were a much more closely related family than the wide variety of aircraft covered by Mr. Driggs.

How did Mr. Driggs make allowances for the difference between the aircraft performance under carefully controlled test conditions and the actual performance obtained in service by the average pilot under average conditions? As any operator knew, there

was a wide difference between the two. B.O.A.C. had frequently termed it the difference between the theoretical performance and the applied route performance.

D. L. Hollis Williams (Fairey Aviation Co. Ltd., *Fellow*): His company found that most time was taken up in determining their basic assumptions. Having once determined those basic assumptions, they found it best in the first instance to build up their performance estimates by direct calculation, as they thought it gave a better understanding of the problem.

It was obvious that any technician when called upon to repeat the same sort of calculation with different basic assumptions on many occasions would introduce his own short-cut methods. In devising such short-cut methods, however, their ingenuity had not equalled the examples described by Mr. Driggs.

Handel Davies (Royal Aircraft Establishment, *Fellow*): It was some time since he was engaged in design analysis work, but he had seen many devices for rapid performance calculation, and Mr. Driggs' method seemed to compare favourably with any he had seen in Great Britain. Methods of that kind had an immense value in estimating changes in performance of existing aircraft and in doing the sort of work which Mr. Dykes had referred to for transport aircraft. But he had always felt that the application of routine methods of that kind to the project analysis for future aircraft, particularly high performance military aircraft, had grave dangers. Mr. Scott Hall had implied that the dislike of that sort of routine method was shared by the project people at the Ministry of Supply; he believed it was shared also by the project people at the Royal Aircraft Establishment.

The reason was that design analysis for future high performance aircraft was primarily a matter of analysing the effects of variations in layout, in plan form, wing section, and so on, on the structural and aerodynamic characteristics of the aircraft. That was where the big problem lay, and nine-tenths of the work involved in trying to decide which line to go for in the design of a military aircraft for a particular requirement was a question of assessing those aerodynamic and structural features.

They might, for example, try to cover a particular military requirement by considering two or three choices—a swept-back wing, with and without a tail, and perhaps a Delta project. In trying to assess the relative merits of aircraft of that kind the difficulties arose in determining the basic drag of the two aircraft, how that basic drag was affected by compressibility, what the altitude performance of the two would be, what the induced factor would be, how the handling characteristics of the two aircraft would compare, and so on. That sort of subtle comparison was difficult to cover by any generalised method.

For example, the suggestion in Fig. 7, that they could regard the drag of the aircraft as being a function purely of the wetted area, was clearly not applicable in comparing two aircraft fundamentally different in their characteristics, such as a large aspect ratio swept-back aircraft like the Boeing B47 and say, a Delta wing aircraft.

For those reasons he believed that most people in Great Britain who were responsible for long-term project planning of that kind would feel that routine methods of the kind described in the paper needed careful handling, in order to ensure that the emphasis was placed on the right things.

Mr. Richards had referred to the effect of sweepback on the span efficiency; the difficulty was that the effect of small differences, particularly in the wing root, were usually so great as completely to mask the small effect of sweepback and of aspect ratio. That again emphasised the main point he was making.

His criticisms did not detract from the value of a method of the kind Mr. Driggs had described for analysing aircraft of a family, such as transport aircraft, and he felt sure that it would have possibilities of application in Great Britain.

L. W. Rosenthal (Saunders-Roe Ltd., *Assoc. Fellow*): Why had the author put the section dealing with weights at the end?

The usefulness of an aeroplane was largely tied up with its weight, particularly so on aircraft powered with gas turbines; on very high speed civil or bomber types, careless or inaccurate weight prediction or failure to meet target weights might well render a project valueless.

In view of that, and the fact that much of the performance data was based upon an assessment of the aircraft weight, it might have been more logical to have laid out the paper the other way round.

Mr. Driggs had performed a valuable service by making available the Buaer curves. He was a little surprised by the very general

approach to the matter of weights, particularly when he considered the immense amount of study and practice which had gone into the development of the performance computor.

Was he right in assuming that less time had been spent on the weight side of the business, or that analysis had proved that a general approach was the only possible solution?

During the war they had become conversant with the American type of weight breakdown illustrated in the preliminary weight table in the paper. As would be expected, it tied up fairly closely with the British M.O.S. Form 2492. They had recently taken surface controls out of the structure group and had included them with the airframe power services, but he believed that in the United States they were considering changing their practice and putting surface controls into the structure group.

The American practice of including the whole of the nacelle and engine mounting in the nacelle group appealed to him much more than the British method of arbitrarily separating those items at the fireproof bulkhead and including some in the power plant and some with the structure.

He believed that on a number of larger machines and up to speeds of 300 m.p.h. or so, the Americans had not been bothered with the torsion component in the wing weight. Could Mr. Driggs confirm that? Had they found it necessary, on high speed aeroplanes, to make some allowance for that?

The wing weight expression appeared to be of considerable interest, but its use depended very much on the correct choice of the design stress factor. Was any work being done to explain more clearly the band of scatter on the design stress factor curve in Fig. 35? In Great Britain recently they had tried to do that, with some success.

A study of Fig. 40 showed that the weights of the tricycle undercarriage fitted on some of the new British civil types were consistently as good as the best American practice.

Working through to Fig. 46, *i.e.* lubricating systems, he was surprised to find such a considerable difference between the weights for landplanes and flying boats; could Mr. Driggs explain that?

They had known for some time that British instrument weights were heavier than American practice, and he believed that an investigation into the matter was to be made. They had no indication, however, that aircraft with gas turbines were any better off in that aspect.

British practice on weight of surface controls (Fig. 49) did not line up at all with American experience, and he felt that perhaps some other important coefficient should be introduced.

British weights for electrical and hydraulic systems (Fig. 50) appeared to be somewhat higher than those of the Americans, and there was in England a growing tendency to be surprised by the weights of those systems. He wondered whether the American designers had more control over their electrical people than they had in this country?

P. J. Ross (R.D. Projects (Weights), Ministry of Supply, *Associate*), *contributed*: Had the effects of design diving speed and relief loads been considered in the formula given for wing weight determination? Were the design stress factors based on the firm's figures or had they been derived by applying the formula to known wing weights?

Figure 37 was a most useful curve and gave reasonable agreement with normal British aircraft. Did any of the plots given relate to aircraft with high-set and swept tail units?

Weights of landing gear for British aircraft had been plotted on Fig. 40, and would appear to be consistently lighter than American components, averaging some 5 per cent. of all-up-weight. Was this in some measure because the majority of U.S. military landing gears were designed for vertical velocities in the region of 15 to 17 ft. per sec., as opposed to the average value of 12 ft. per sec. for British types?

It was understood that even greater values of vertical speed were being considered for U.S. shipboard aircraft. In order to achieve this value, was any relaxation proposed of the "landing weight" defintion, *i.e.* was it possible to state whether the bomb load was included in this term, and what percentage of the gross fuel was assumed for landing?

U.S. values appeared to be heavier than those for British aircraft; would Mr. Driggs give some idea as to what was actually included in the U.S. breakdown on controls?

Mr. Driggs had referred to an empirical formula for determining power plant weight; similar work had already been done in Great Britain, the results of which were contained in Tech. Note Aero 1940 S.D.73.

H. C. B. Thomas (Ministry of Supply, *Assoc. Fellow*), *contributed*: If Fig. 39 were superimposed on Fig. 38 the curve of hull weight almost coincided with the 400 kts. fuselage weight or some 38 per cent. above the 300 kt. curve. Since the curve of hull weights must have been based on boats of 300 kts. or less, did the author conclude hulls would be 38 per cent. heavier than the approximate similar shape of landplane fuselage?

In Fig. 39, the use of $L(B+H)$ would show high weights for hulls of a high length/beam ratio. Perhaps the use of LBH would overcome this difficulty.

C. F. Toms (Bristol Aeroplane Co. Ltd., *Associate*), *contributed*: The lecturer was to be congratulated on presenting a paper which combined a detailed technical treatment of the analysis of an aeroplane design with remarks which, if absorbed as fully as the technical matter, should prevent the methods and data (in particular the latter) from being mis-applied by the less experienced.

The reference to the value of estimates was likely to be mis-understood unless it were realised that the primary function of a division, such as that headed by the lecturer, differed from that of an aircraft design organisation. The Research Division had to determine which of a number of horses in a race was in the lead, while the design organisation had to bring its own particular horse to the highest possible pitch of efficiency. The latter task involved a continuous attack on the frontiers of aeronautical knowledge, and to organise such attack effectively, analysis was essential. The analysis might not give the right magnitude, but it would indicate the best direction of attack.

Although the performance slide rule provided a complete performance solution for a given aeroplane more rapidly than did an elementary graphical process, many of the problems arising in design work were of an isolated nature, and were more readily solved by special methods of calculation.

Was any mechanical aid used to facilitate the manipulation of the three separate plates of the logarithmic performance slide rule?

Would the lecturer indicate the values to be marked on scales of Figs. 24 and 25?

G. H. Lee (Handley Page Ltd., *Assoc. Fellow*), *contributed*: He thought it would be of interest to report on the experience that Handley Page Ltd. had had when actually using the apparatus that Mr. Driggs had kindly placed at the disposal of the Royal Aeronautical Society.

They had used the "slide rule" both in its "power" form as applied to a piston-engined aircraft and also in its "thrust" form as applied to jet-propelled machines. They could not give any detailed comments on the method as they had only worked out one example in each case, but from what they had done, it appeared that the method did everything that the lecturer said it would and they thought that it was a technique with considerable possibilities.

It seemed that the lecturer's method for the calculation of jet-engined aeroplane performance would be useful in doing climb calculations when the distance covered and the fuel used in climb to a specified altitude had to be worked out. This had to be done in assessing the range performance of a jet-propelled areoplane and was quite important as an appreciable quantity of fuel was consumed on the climb. It seemed to them that this method might be considerably quicker than the, more or less, straightforward methods that they had had to use up to the present.

Some people had seemed to give the impression that firms were not concerned with studying performance of a series of different aircraft. While it was true that most of the work in a firm was concerned with the performance of one specified machine, it was also true that in the early design stages, when an attempt was being made to meet a given specification, a whole series of different aircraft had to be studied in order to arrive at the optimum design. For this purpose, the method proposed by Mr. Driggs would undoubtedly be very valuable, even if it were not used greatly for the more detailed subsequent calculations.

MR. DRIGGS' REPLY

His method of performance analysis was not a generalised method; it was a means for drawing a power-required curve on paper, just as they now arrived at such a curve by detail computation and then plotting. It applied to swept-back, straight wing, Delta wing or any other aeroplane which had both induced and parasite drags. They could take a French curve and draw a line through a series of calculated points and would get the same line as obtained by the use of methods outlined.

The Aerodynamics and Hydrodynamics Branch of the Bureau of Aeronautics, which was charged with the computation of the performance of all aircraft designs submitted, used the method he had described. He had had to take some trouble in selling it, but it was adopted finally because that branch had so many aircraft to analyse that they could not deal with them all in the time available unless they used some such method. Nowadays they would not use anything else.

The method was not a generalised performance chart in the usual sense, but simply a means of drawing a line on a piece of paper, the movements of the various overlays taking the place of the many detailed computations required in the usual procedure.

The logarithmic method of performance analysis drew so much similar comment that it seemed wise to answer all those comments at one time.

As he had already stressed, the methods proposed were by no means a generalised, graphic series of performance curves. The power-required curve of Fig. 1 automatically performed a series of detailed calculations which involved the computation of power required to overcome both reduced and parasite drags. The placing of this graph over a logarithmic chart of power available and its movements upon that graph performed all of the other calculations that were required for changes in weight, altitude, parasite area, effective span or engine characteristics caused by inlet or tail pipe losses. The results obtained were numerically identical to those that would be determined by detailed calculation in the usual manner. The shape of Fig. 1 and the placing and movement of this graph defined in mathematical terms the arithmetical processes that must be followed in order to obtain the performance of any aircraft which might be defined by the two parameters given. Therefore, the same accuracy could be expected as when each point on a series of power-required curves was calculated and plotted in the usual manner.

It was realised that the estimation of the parasite drag and the span efficiency factors were of great importance. In submitting the logarithmic performance methods, it was not intended to imply that such was not the case. It did appear, however, that a method of obtaining actual performance numbers by the means outlined, rather than by detail calculations, would allow more time for an engineering group to concentrate upon the more important problems. To depend on routine calculators to determine the performance changes resulting from small variations of aircraft or engine characteristics had been found to slow up the process of deciding upon a new aeroplane design to such an extent that the designer lost his perspective. In the Bureau of Aeronautics they were interested in more than one aspect of an aircraft's performance. It was necessary to consider its operational utility in a series of typical combat problems, each one of which required a serious amount of computational effort unless done by some such means as given in the paper.

The estimation of the parasite area and the span efficiency factor, similar to the estimation of weights, was based upon flight test statistics of actual aircraft; the data given on Figs. 7 and 8, consequently, were not as complete as they might wish. Therefore, it had been impossible to isolate many secondary effects which undoubtedly would have significant bearings upon the values. By comparison of a new design with an older one for which values of f and e had been determined, good results might be obtained.

He thought that many aircraft designs must be conceived, analysed and discarded before a final decision was reached as to the best type to be built. This statement applied both to the government agency which was responsible for the specification and to the contractor who tendered a proposal to meet that specification. In such analyses, many factors must be considered; high speed alone was but one and probably not the most important; combat radius, rate of climb, absolute ceiling, combat ceiling, fuel used in climb, were all items that must be determined for any design before it could be evaluated operationally. Other factors such as cost, armament, fire power, manœuvrability, must also be considered but those points were beyond the scope of the paper.

After an aeroplane design had been decided upon, the computation of the performance might be done by the logarithmic method or detailed analyses could be employed. The results in the two cases would be identical but considerable time would be saved by using the logarithmic graphs.

As he had said, a Division in the Bureau of Aeronautics, concerned with the perform-

ance analysis of contractors' aircraft, had adopted the methods described as a means of time-saving. The American Aircraft Industry had not been supplied with this information before his lecture was delivered. Subsequently, copies had been given to all contractors and they might use the methods in their own performance submittals to the Bureau if they wished. If they should do so, not only would their own work be reduced but also that of the Bureau of Aeronautics in checking their computations.

Mr. S. Scott Hall: The estimation of the critical Mach number and the compressibility drag rise was the subject of continuous study in the Research Division. To have reported sufficiently upon those matters would have required a separate paper. Fig. 5 was intended largely for illustrative purposes, assuming that each engineer would have developed his own methods of estimation more or less empirically from his own experience. This figure was the result of considerable analysis of flight tests in the Bureau of Aeronautics and seemingly had given reasonable results. Those data or any other similar material might be used with the logarithmic charts which were completely flexible.

For an estimation of the speed at which the drag started to rise and the shape of the drag rise curve at higher speeds, both wind tunnel tests and flight tests of their research aircraft were being employed. It was hoped that at some future date this material would be sufficiently analysed to warrant a comprehensive report upon the subject.

Equation (44) for wing weight did not include a factor for torsional effects. However, good results had been obtained by the use of those data by choosing information obtained from aircraft similar to a proposed design. The Research Division was currently working on this problem and hoped to be able to include additional factors to account for torsion relieving loads and so on.

In general, the weight data presented in the last Section of the lecture was presented on a series of graphs rather than in tables because a more comprehensive picture could be obtained quickly in this manner. Plotting armament weight against gross weight did not mean to imply any necessary relationship between those two quantities but was simply a means of presenting information.

Mr. E. J. Richards: In the United States they had not yet been confronted with the problem of reducing aircraft performance with propeller turbines to standard conditions, although work had been done for turbo-jets. This matter of the propeller turbine would arise sooner or later and it was evident that some thought must be given to it; but at the present time, no information was available. It was believed that a scheme based upon pressure altitude with corrections for ambient temperature variations from standard might be found to be effective. This implied that the relative density as normally used in aircraft and engine analyses be changed to its equivalent, the ratio of the relative pressure to the relative ambient temperature. This was the relationship used in the lecture in order to maintain like terminology for the aircraft and engine. This same substitution might be made in the case of the propeller performance. Figs. 24 and 25 demonstrated that turbo-jet generator performance could be reduced to sea-level static conditions from data obtained from a series of altitudes and speeds. It appeared reasonable that a turbo-propeller generator could be handled in a similar manner. Those were primarily suggestions, since no comprehensive study had been made on this matter.

Mr. A. E. Woodward-Nutt: It was unfortunate that specific aircraft could not have been indicated for the various points on the weight curves. That was not possible in an open meeting but he would be glad to furnish Mr. Woodward-Nutt with any specific information that he desired. As mentioned in reply to Mr. Scott Hall, the graphical presentation of the weight data was employed merely as a means of presenting statistical information, believing that a graph was more comprehensive than a table. Logarithmic scales were used in order to reduce the size of the charts. There was no intent to imply that an exponential law existed between the various parameters on those weight charts.

Mr. J. Cohen: The Research Division had also constructed a slide rule for quick performance analysis, probably very similar to the device used by Mr. Cohen. It was found, however, that there was insufficient flexibility to cover all the problems which arose. Consequently, it had to be discarded in favour of the logarithmical graphical solution described in the lecture.

Mr. C. Dykes: Mr. Dykes' experience that one girl computer to each engineer was

necessary was interesting. Was this necessity one of morale or of proper accomplishment of the job? If the former, he agreed most heartily, but if the latter were the case, they had found in the Navy that the logarithmic performance methods were considerably more effective, in that they kept the engineers more closely in touch with the progress of a design.

He had not discussed take-off, although relatively simple procedures were employed for estimates of carrier take-off. Problems of climb, whether immediately after take-off, *en route*, with all or part of the engines operating, were analysed by the logarithmic graphs. The landing conditions were not included.

He would be glad to receive comments on the engine performance analysis calculations outlined in the paper. Unfortunately, such comments had not been received so far but he believed there were some engineers who would like to take issue in that connection. Comments would be welcomed.

It was not the function of the Research Division to make allowance for performance obtained under other than ideal conditions. Consequently, Mr. Dykes' last comment could not be answered specifically.

Mr. Handel Davies: He believed that Mr. Handel Davies' comments had already been answered.

Mr. L. W. Rosenthal: He had not intended in his arrangement of subjects to imply that weight estimation was not important.

Considerable time had been spent by the Research Division in collecting and analysing weight information but so far the statistical approach as given in the lecture had given better results than any other that had been devised. Work was continuing, however, and it was possible that a more rational analysis might be possible.

The lower weight of lubricating systems for flying boats had not been thoroughly explained. Mr. Rosenthal would have to accept the information given as a factual reporting of observed data. It was possible, however, that this difference might be due to the specifications for oil system capacity and arrangement for the two types.

Mr. P. J. Ross: The wing weight formula given did not consider the effects of design diving speed or relief loads. The design stress factors were obtained by working back from reported wing weight and were not based upon the contractor's design stress figures. None of the weight data in Fig. 37 applied to high placed tail surfaces, although some swept tail units were included.

It was true that American aircraft were designed for high vertical velocities in landing, but under those conditions it was not assumed that the full load would be landed. In the Navy they considered that the 17/ft./sec. vertical velocity applied to training operations in which the pilots were making their carrier qualifications trials. Under those conditions full armament was not carried. It was assumed that nearly full fuel would be aboard.

The surface control group included every unit that was included in the aircraft structure incident to the control system, that was, all brackets, cables, rods, bell cranks, pulleys, and so forth. Mounting structures required specifically for the controls were also included.

He would be interested in comparing the United States Navy results with the Ministry of Supply empirical formula for determining power plant weight.

Mr. H. C. B. Thomas: The comparative data for hull and fuselage weights had been obtained statistically and, consequently, hull weights for 300 knot boats appeared to be of approximately the same weight as 400 knot fuselages. The only conclusion that could be reached from those data was that hulls had been heavier than fuselages of the same dimensions. Considering the bottom loads of the hull, this result should not be unexpected. It was possible that when they had a sufficient number of hulls of high length/beam ratio they might find that some other combination of the length beam and height might give a better grouping of points. Until sufficient information of this kind was available, it did not seem that any change was desirable. The combination of dimensions used, if multiplied by an appropriate factor, would give the hull surface area, while the dimension of the combination suggested by Mr. Thomas would result in a factor proportional to the hull volume. It appeared that the former was somewhat more logical.

Mr. C. F. Toms: The Research Division of the Bureau of Aeronautics operated in exactly the same manner as an aircraft contractor. That Division was but an aircraft design organisation transplanted from various contractors' design staffs to work in the Bureau of Aeronautics. Their work consisted

largely in designing aircraft to meet a very general desire for improvement in naval aeroplanes prior to the issuance of a specification to the Industry, with a request to tender proposals for construction. The Research Division endeavoured to ensure that those specifications, when issued, were possible of attainment and that the resulting designs submitted by the contractors could be of use to the Bureau of Aeronautics. The Research Division was not interested in the final evaluation of those designs in a direct manner; that was, they did not determine the leading horse in the race, but rather set up the rules under which the race should be run. The function of checking the designs submitted by the contractors was performed by another division in the Bureau which, as had been previously indicated, employed the logarithmical method of this checking.

As yet, no mechanical aid for the manipulation of the three separate overlays had been worked out, although they had thought of numerous ways how this might be done. As they had no experimental shop within the Bureau of Aeronautics, it had been difficult to try out any of these ideas, but in case any of the firms in Great Britain should do so, they would be very pleased to receive photographs or other information regarding the results of such experiments.

Since the data of Figs. 24 and 25 applied to a jet engine which was still in a confidential status, it was impossible to supply the numerical co-ordinates for those figures. Those data must be considered as illustrative only, for the time being.

Mr. G. H. Lee: He was very glad that Handley Page Ltd. had applied the logarithmic performance methods and had had favourable results. He had no reason to believe that other trials, whether by Mr. Lee or by other engineers, would not give like comparisons.

Mr. Lee evidently approached the problem of designing an aeroplane to meet a given specification, much in the same manner as was done in the Research Division—namely, by designing a series of aircraft more or less on a trial and error basis until a satisfactory design could be chosen. As pointed out previously, the logarithmic performance methods lent themselves ideally to that type of problem.

PRACTICAL TRAINING OF AERONAUTICAL ENGINEERS

by

J. M. HAHN, B.Sc.(Eng.), Grad.R.Ae.S., G.I.Mech.E.

THE MEN who could best lay claim to the title of "Aeronautical Engineer" were the early pioneers like Wilbur and Orville Wright. They were their own research workers, their own designers, their own draughtsmen, their own constructors, their own test pilots and, later on, their own salesmen. The Wright brothers carved and steamed the bamboo ribs and struts of their aeroplane themselves, brazed and spliced the wires and cables, while their sister Kathleen stitched the flimsy fabric. But the day of the craftsman-designer is gone.

This paper is concerned with the present-day professional aeronautical engineer in industry and in particular, with the aircraft designer. A distinction must be drawn between the aeronautical engineer and the aircraft technician; both may be intimately concerned with the design of an aeroplane, but the technician—the stressman, the aerodynamicist, the draughtsman—is at the most an embryo aeronautical engineer.

By an aeronautical engineer I mean an individual qualified to do, and capable of, work involving a high degree of personal responsibility; a man who may be called on to decide upon and implement the policy of his department, to play a major part in controlling the design, manufacture, or sale of his firm's aircraft, to direct research or development programmes, and to supervise and control employees. It is on this type of man that the responsibility falls of maintaining the high rate of technical progress which is an outstanding characteristic of the Aircraft Industry.

Despite the fact that as the Aircraft Industry has grown the posts within it have become increasingly specialised and departmentalised, the function of the true aeronautical engineer remains the same as it always has been: to see that his firm produces aeroplanes — good aeroplanes, cheap aeroplanes, aeroplanes that can be built quickly, and aeroplanes that are not too expensive or too difficult to keep in service. The phrase "cheap aeroplanes" should be emphasised; so many technicians and engineers overlook the fact that aircraft engineering is a commercial business. The primary function of an aircraft firm is not just to make aeroplanes but, having made them, to *sell* them for rather more than they cost to build.

The universities in future must be the Industry's chief source of supply for professional aeronautical engineers. The design, manufacture and development of the modern aeroplane cover a technological field of wide extent and complexity, and the aeronautical engineer must have a broad and fundamental scientific training and a thorough understanding of, and an ability to apply instinctively, the basic principles of engineering science. Above all, he must have a well-trained mind and a realistic scientific outlook. These qualities are best developed by a full-time course at a university, followed by graduation with an engineering or science degree.

Although the mathematical and scientific tools with which a university equips its graduates are strong, and the trained mind which the university produces is essential if the engineer is to cope with the varied and difficult problems of building aeroplanes, the

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academic studies of a young engineer by no means constitute the whole of his training.

The aeronautical engineer, to fulfil his function in industry efficiently, must have a full and intimate acquaintance with the most important manual operations involved in aircraft construction, a basic knowledge and thorough understanding of the factory processes and techniques, and must be familiar with the internal organisation and basic structure of the aircraft factory. To no class of aeronautical engineer do these remarks apply more than to the man directly concerned with the actual design of the aeroplane and, in the author's opinion, this part of the training of the aeronautical engineer is also a basic requirement of the qualifications needed by a junior aircraft technician. The technician in the Aircraft Industry, while he does not carry the responsibility of making the far-reaching decisions which the true aeronautical engineer is called upon to make, nevertheless is entrusted frequently with responsible design or development work, and the decisions he makes can save or cost his company many thousands of pounds in the long run, according to how well or badly he performs his job.

In the author's opinion any man whose job is to be the design of aeroplanes—from the junior stressman making a minor modification to a small door, to the chief designer responsible for the overall design of several large projects—should have a thorough practical workshop training. How else can he acquire that wide store of *practical* experience, that instinctive appreciation of the *practical* difficulties of manufacture and maintenance, that intuitive knowledge of what is *practically* reasonable, which are so sadly lacking in many design offices today?

It has been said that the design office must always keep two or three years ahead of the works, but unless designers fully comprehend the potentialities and limitations of the existing factory techniques and equipment, how can they know whether they are twenty years ahead or ten years behind? There is a fundamental antagonism between the aircraft designer and the production engineer, who in the very nature of things will try to keep a design static, while the designer knows that his machine may be obsolete after two or three years unless continual modifications are made to the original design. This fundamental antagonism could be reduced if the design staff had a greater appreciation of the difficulties and problems of the production engineer: such bugbears as complicated and intricate detail parts, cramped and inaccessible final assemblies, shortages of material and plant, lack of sufficiently skilled labour, and so on.

The objects of a course of practical training, therefore, considered as a necessary complement to the academic training of an aeronautical engineer, are as follows:

(*i*) To familiarise him thoroughly with the manufacturing processes and techniques used in the fabrication and construction of aircraft.

(*ii*) To help him to appreciate fully their practical limitations and future potentialities.

(*iii*) To acquaint him with the difficulties of manipulation and treatment of the materials currently used in manufacture.

(*iv*) To provide him with a knowledge of the machinery, plant, equipment and skill available for the manufacture of the firm's aeroplanes.

(*v*) To help him to understand the outlook of the workmen who will build his designs, to see their point of view and to understand their psychology and philosopy; and to help him to learn a little of the human problems of the different types of workers and staff, whom, one day, he may have to control and direct.

(*vi*) To acquaint him with the general structure of the industrial organisation of which he is a member; to see in all its practical detail the complex industrial machine at work, to give him the opportunity of finding out from shop foremen and superintendents the functions, importance, and difficulties of the various departments and services.

(*vii*) To further the liaison between the various departments of the factory. The following is an extract from a paper read before the Royal Aeronautical Society by the works superintendent of Handley Page Ltd.*:—

" . . . . The successful manufacture of any article, and in particular, of an aircraft, depends largely on close liaison between

* Some Developments in Aircraft Production, D. C. Robinson, JOURNAL of the R.Ae.S., January 1949.

design, production, and inspection. This liaison must exist at all times, from the inception of the design, through the project and experimental stage, drawing office and experimental shops, to the production line. The works must play a large part in settling the way in which the major part of the design is schemed to be produced, and the drawing office must be production-minded. This close contact should bring about a large degree of confidence between design office and works, and a respect for the other's point of view when at variance on any particular problem . . . . "

That is a point which is frequently overlooked in assessing the value of practical workshop experience, and yet this liaison is an all-important factor in the smooth running of a factory. How can it be achieved? The percentage of young workers who have sufficient scholastic ability to work their way, by means of apprenticeships and scholarships, from the shops to the design offices is negligibly small. Then, designers must go into the shops, if only for a brief spell. There is no need for them to acquire manipulative skill; that is no part of the aims of a practical course for the embryo aeronautical engineer. But only by performing with his own hands the various tasks and operations involved in aircraft construction can he begin to understand the problems and difficulties of the men whose job it is to build the aeroplanes. He must not be a mere passive observer in the shops; he must take an active part in their work. During his training, he must be *of* the shops and not just *in* them.

The practical training of an aeronautical engineer is best achieved by means of a post-graduate apprenticeship of at least a year's duration; several of the major firms in the Industry run such courses, but even today many of those technicians and designers who do acquire practical experience do so in far too lax and casual a manner.

The graduate apprentice should follow a properly organised and carefully planned course which will enable him to work in all the relevant manufacturing and development departments of the factory. He should spend sufficient time in each department to enable the older members of the shop supervisory staff to take an interest in him and to give him the benefit of their experience and knowledge in helping him to understand the functions and the problems of the shop. He should be assisted in every possible way to understand the intricate network of the internal organisation and services of the factory, and to appreciate the functions and work of the shop foremen and superintendents.

To encourage him to seek information for himself, and to systematise his training, he should be expected to submit reports on his experiences in each department; these reports should be submitted to some such person as the apprentice manager, who would take a critical interest in him and his work, and who could guide and advise him on the details of his course.

The author considers that the most appropriate time for a young engineer or technician to take such a course is after he has graduated from university and preferably, after he has had some experience of design, development or research work within the Industry itself. Many firms recommend that a student apprenticeship course of one or two years' duration be undertaken immediately before entering the university, but the author feels that this involves a most unsettling and undesirable discontinuity in an engineer's academic training. Besides, a university course, among other things, trains a man to work by himself and for himself, teaches him how to observe and collect systematically facts and acquire knowledge, and gives him the necessary objective approach to a course of this kind. The graduate's office experience will assist him in knowing what to look for and what to study when subsequently he " serves his time " in the shops.

When the graduate or student apprentice finally leaves the shops, he should not forget the friends he will have made there, or allow to lapse the many useful contacts he will have acquired. How often does a draughtsman or a stressman ask the shop foreman's advice on some detail of manufacture? When a new process is introduced into a factory, how many designers or draughtsmen see anything of it but a printed brochure and a small demonstration sample? When a technician is handed two pieces of dural, six inches by two perhaps, carefully joined together with a new type of rivet by some enthusiastic research engineer working in the cloistered seclusion and laboratory conditions of an experimental department, how can he gain any idea of the *practical* advantages and disadvantages, the

practical limitations of the process? When a new manufacturing technique is introduced any member of the design or production staff concerned with it should have the opportunity, if only for a few hours, of seeing the process in action and perhaps even of performing the operations involved.

The lack of practical experience is only one aspect of the serious deficiencies in all-round experience which handicap many technicians today and which prevents them from developing into true aeronautical engineers. Many young technicians, arriving in, say, the stress office of a large firm, are put straight on to extremely specialised work (and this in a branch of engineering which is itself a narrow and specialised field). What does he see of the other departments of the firm? If, in the early part of his career, he is kept continuously on the same class of work, how can he acquire any sense of proportion, especially in a large firm where specialisation and sub-division of functions is carried to extreme limits? The facilities for enabling young technicians to complete their training and to become fully fledged aeronautical engineers are at present poor. They must be improved if the supply of able and responsible senior personnel is to be maintained.

That is the case for the training of the aeronautical engineer. The universities will supply him with his pound of theory—it is up to the Industry to see that he gets at least his ounce of practice.

THE MILITARY AERO-ENGINE—IS IT SUITABLE FOR CIVIL AVIATION?

by

S. B. BAILEY, M.Sc.(Eng.), A.F.R.Ae.S., A.M.I.Mech.E.

INTRODUCTION

In the past, the majority of civil aircraft have been powered by engines which have been developed primarily for the Royal Air Force. Their development costs have been borne by the Service departments, and then they have been converted for civil use at comparatively small extra cost.

It has always been questionable whether these converted engines have been really suited to their civil role, and it will become even more doubtful the farther the design and performance of civil aircraft depart from those of military aircraft.

In this paper, an attempt has been made to cover the more important requirements for the two kinds of engines, and to see how they compare. If it appears that too little has been said concerning the gas turbine, that is because there is as yet no experience of its commercial operation.

The opinions expressed in the paper are the author's and have no official significance.

MILITARY ENGINES

In considering whether aero-engines which were developed initially for military use are suitable for conversion for civil aviation, it must be made clear what is meant by a "military" engine. Military engines may be installed in aircraft which are operated as fighters, bombers, or for reconnaissance, and the requirements for each type of work are different.

(*a*) *Fighters*

An aero-engine used in a fighter must have the following qualities in order of importance:—

(*i*) performance.

(*ii*) the ability to give take-off power in the shortest possible time after starting up from cold.

(*iii*) invulnerability to light machine gun fire.

(*iv*) reliability.

(*v*) fuel economy under cruising conditions.

(*vi*) ease of maintenance.

A fighter which has a performance inferior to its adversary is useless, as it will be shot down. Its engine must give the maximum possible power consistent with sufficient reliability to maintain the pilot's confidence in his aircraft. The requirements differ in proportion according to the exact function of the fighter, in that it is possible to sacrifice more reliability for a short-range interceptor fighter than for a long-range escort fighter in which engine failure will probably result in loss of the aircraft and its crew.

The relative importance of item (*v*) depends upon the exact role in which the aircraft is used. In the interceptor fighter, ultimate performance is the aim and endurance will usually be sacrificed to achieve it. The escort fighter must have long range and it may be possible to achieve this by developing the interceptor fighter engine so that it will operate satisfactorily over a wide range of power and r.p.m., and by the use of jettisonable fuel tanks.

Ease of maintenance has been put last only because the other requirements are of a paramount importance. Unless the engines can be easily maintained in the field under wartime conditions, aircraft serviceability will suffer and it will not be possible to keep squadrons up to fighting strength.

(*b*) *Bombers*

Engine requirements for bombers are rapidly changing as speeds increase, but if

Paper received August 1949.

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the heavy bomber of the 1939-1945 War is considered, the most desirable engine qualities were:

(*i*) reliability,

(*ii*) { performance / fuel economy

(*iii*) invisibility of exhaust at night,

(*iv*) invulnerability to shell splinters and light machine gun fire,

(*v*) ease of maintenance.

Reliability has been put before performance because the heavy bomber is so slow compared with contemporary fighters that it owes nothing to speed for its safety. A heavy bomber aircraft which is operating at the maximum all-up weight permitted by airframe structural considerations will gain nothing from increased engine performance; in such an aircraft, engine unreliability will decrease the operational effort by causing the aircraft to be withheld from operations because of unserviceability, or by causing premature returns from sorties. On the other hand, a heavy bomber aircraft the take-off weight of which is limited by engine power availability, will profit considerably from an increase in engine power; it may pay to operate the engines in such an aircraft at increased power (with a consequent reduction in reliability and life) for the sake of increased bomb load per sortie, or increased weight of bombs dropped per aircraft lost.

Here again, ease of maintenance is far from the top of the list, but it is still of great importance. Under wartime conditions, the factor which limits the national effort is availability of man power, not only in the field but in the factory and repair shop. Every engine which fails in service requires replacement by a new or overhauled engine, involving the expenditure of man hours by the maintenance crews and the manufacturers or repairers. The effects of an unreliable engine are felt first by the air crews who have more than sufficient anxieties without being worried by engine failures which may sometimes occur when they are least welcome (*e.g.* during take-off with a heavy bomb load; when climbing through icing cloud; or when trying to maintain altitude over heavily defended areas). A series of failures can easily undermine the confidence of the crews in their aircraft, with serious results; an example which may be cited from the 1939-1945 War is the effect on morale which was caused by the installation in operational heavy bomber aircraft of certain aero-engines which had been overhauled to such a low standard of quality that their failure rate was nearly three times that of new engines of the same type, a fact which started crews discriminating against aircraft with overhauled engines.

Before the introduction of quickly detachable power plants, a high engine failure rate resulted in much extra work for the ground crews, and in reduced aircraft serviceability; this was immediately reflected in a reduced operational effort. The quickly detachable power plant removed most of this extra work from the squadron maintenance personnel, but it had to be done somewhere, either by Service personnel in regional depots, or by repair contractors. The operational effort, therefore, did not suffer immediately as a result of a high rate of engine failure, but more and more work was required from the power plant reconditioning shops and, in time, these became bottle-necks which held up supplies of serviceable power plants to the squadrons. Such bottle-necks were easily remedied by the transfer of maintenance personnel from the squadrons to the power plant overhaul bays, but the whole process ultimately was limited in scale by the man power available to change the power plants in the aircraft, to change the engines in the power plants, to overhaul such of the engines as were repairable, and to make new engines to replace those which could not be repaired.

(*c*) *Reconnaissance aircraft*

In the past, reconnaissance aircraft have been of three main types:—

(*i*) slow, manœuvrable aircraft for gun spotting.

(*ii*) photographic reconnaissance aircraft for strategic bombing intelligence duties.

(*iii*) long-range reconnaissance aircraft for Coastal Command duties in liaison with the Royal Navy.

Engines required for the first type are small and of no interest for civil transport. The second type is usually a converted escort fighter, with similar power plant requirements, except that it may have to operate at greater heights. The large aircraft for long-range reconnaissance is of great interest to the civil aircraft operator, as its engines have at least two requirements

in common with his, namely: reliability and low specific fuel consumption.

CIVIL ENGINES

The more important requirements for aero-engines for civil air transport may be listed as follows in order of importance:—

(*i*) Reliability.
(*ii*) Economy.
(*iii*) Ease of maintenance in service.
(*iv*) Performance.
(*v*) Simplicity of operation and handling.
(*vi*) Ability to operate anywhere throughout the world.

(*i*) *Reliability*

Reliability has been put first, primarily from safety considerations, and secondly for economic reasons. The need for safety in civil aircraft operation is obvious and does not need further explanation; unless civil aviation can be made so safe that the danger of accident per passenger hour is comparable with that pertaining to other means of transport, it will never become popular. Engine reliability is essential to aircraft safety.

The effects of engine unreliability on economics are extremely serious, not so much because of the expense of repairing failed engines, but because of the aircraft delays which are involved in unscheduled engine changes and petty engine unserviceability.

(*ii*) *Economy*

Under this heading come:—

(*a*) the first cost of the engine.
(*b*) the service life of the engine.
(*c*) the cost of overhauling a time-expired engine.
(*d*) the specific fuel consumption of the engine, and the cost and weight of the fuel used.
(*e*) the cost of routine maintenance of the engine.
(*f*) the cost of an engine change in terms of man hours required and loss of aircraft utilisation.

All these are inter-related; it may be economical to sink more capital in the first cost of an engine if by so doing its service life can be increased, or its fuel economy improved. The same principles apply, to some extent, to a military engine, but military engines normally have high wastage rates because of aircraft losses in war, and there is no point in designing the engine to give a service life which it will never have the opportunity to achieve. The civil operator expects a service life of at least 600 hours from conventional reciprocating engines, and he does not expect to have to change cylinders, magnetos, or constant speed units during this time.

(*iii*) *Ease of maintenance*

The civil aero-engine must be capable of running its full life without the necessity for periodical adjustments requiring highly skilled labour. Given foolproof torque-limiting spanners, spark plug changing is not a highly skilled operation and, given reasonable accessibility, can be tolerated every 100 hours for the sake of optimum performance. On the other hand, operations like tappet adjustment consume far more time and require more skilled personnel; reliable automatic tappet adjustment would be a boon to the civil operator who wants to save the man hours involved. The extra prime cost would be worth while, as the civil engine may be expected to remain in service (including periodical complete overhauls) for thousands of hours.

The need for periodical maintenance operations will never be completely eradicated, but such operations as remain must be made as simple and rapid as possible. Oil and fuel filters should not require inspection and cleaning more often than every hundred hours; it must be possible to remove them without spilling fluid on the operator, on the aircraft, or on the hangar floor.

Turbine blade clearances will require periodical checking so long as the materials used continue to creep at the operating temperature and stress; it must be possible to make this check within half an hour, and this will involve electrical measurement or quickly detachable tail cones. If combustion chambers seriously limit the engine life, it must be possible either to change them easily *in situ*, or to remove the complete engine and replace it within an hour so that the cams can be changed without holding up the aircraft.

All these maintenance points apply equally to both military and civil engines. The military engine has an over-riding

requirement in that it may be handled by relatively unskilled personnel in time of war; the civil engine, because time is money, and every unnecessary hour spent on routine maintenance must be subtracted from the useful working life of the aircraft in which it is installed.

(*iv*) Performance

The engine performance requirements for civil aviation find their counterpart in the military transport and long-range reconnaissance aircraft—or at least they have done so heretofore. The position may change as the operating heights of long-range civil aircraft increase, because they will then employ pressure cabins in all cases. The military transport may not be able to employ a pressure cabin on account of its extreme vulnerability to anti-aircraft and cannon fire, and such aircraft may therefore be compelled to operate at a height where the provision of oxygen will suffice, without pressurisation.

Even should there be no change in the relative performance requirements, it is becoming increasingly difficult to adapt British military engines to civil use because of International Civil Aviation Organisation (I.C.A.O.) requirements, which apply only to civil aircraft. In Great Britain, military engines for many years have obtained high take-off or combat power by the employment of high piston speeds and high boost pressures, and they have accommodated the high thermal loading involved by using very rich mixtures, or liquid cooling, or both. Manufacturers in other countries, notably the U.S.A., France and Germany, have obtained similar take-off powers for similar weights (but with increased frontal area) by using larger engines of a lighter construction and employing lower piston speeds and manifold pressures. The mechanical loading on the British engines at take-off has been high, but they have been able to survive the official type test as only 10 hours of this test have to be run at take-off power.

The position is very different where maximum continuous power is concerned. Eighty hours of the type test have to be run at this power, and a further 40 hours at stated percentages of it, making a total of 120 hours' running at powers proportional to the declared maximum continuous power. The mechanical loading on the engine largely determines its ability or otherwise to survive this 120 hours and, in consequence, the small, highly loaded British engines seem to be incapable of carrying quite such high continuous powers as contemporary American engines of similar take-off power. The I.C.A.O. requirements for minimum rate of climb after a single engine failure, place a premium on high maximum continuous power rating, and it seems doubtful whether the highly loaded British engine will be able to compete with its bigger American brother of similar take-off power. The British practice, born of military fighter development, encourages high combat power for small frontal area, but leads to the installation in civil aircraft of engines which are too small to provide the required cruising power combined with reliability and long life.

Turning from reciprocating engines to gas turbine engines, it is evident that the propeller-turbine would form a suitable power plant for the heavy bomber; whether there is any future requirement for the heavy bomber is another matter. If all future bombers are to rely on speed and height for their safety against attack, jet propulsion and pressure cabins will be used, and the engine performance requirements will be similar for both long-range civil and bomber aircraft.

It appears that the only field in which there may be no parallel requirements for civil and military engines will be that of the high altitude propeller-turbine engine, which will be peculiar to the medium-speed civil aircraft, unless the operational risk of pressure cabin transports flying at great heights is accepted by the Royal Air Force.

(*v*) *Simplicity of operation and handling*

It is desirable that as many engine controls as possible shall be entirely automatic:

(*a*) so that there shall be no possibility of their being incorrectly handled, and

(*b*) to relieve the crew of routine "control juggling."

provided that:—

(*a*) the automatics can be made 100 per cent. reliable in operation, and

(*b*) they really do perform the function for which they are installed.

In this connection, it is worthy of note that many so-called automatic boost controls function correctly over very limited boost ranges, and that the most perfectly designed carburettor cannot cater for the

idiosyncrasies of particular engines. Carburettors which have been developed from the Royal Aircraft Establishment type (sensitive to r.p.m., boost pressure, charge temperature, and exhause back pressure) function admirably with a standard engine, but it is considered that a manually controlled variable datum to such a carburettor would be worth fitting when power or torque meters are provided.

(vi) *Ability to operate anywhere throughout the world*

In order to achieve the highest possible operating economies, it is desirable for an aircraft to be specially designed for the particular route over which it is to operate. However, future trends of traffic are extremely difficult to forecast, affected as they are by politics, wars, trade slumps, and so on, and it can never be guaranteed that any aircraft will remain throughout its life on the route for which it was designed. In consequence, the engines may be called upon to operate anywhere from tropical summer to sub-Arctic winter conditions. They must be capable of starting from cold at temperatures down to -40° C. and, at the opposite end of the scale, adequate take-off power must be available with an air cleaner in circuit at an air temperature of $+40^\circ$ C.

Military engines have fallen short of these ideals in the past, and aircraft performance in tropical conditions has sometimes been marginal. The civil engine must take these variations in it stride, and must be quickly convertible from temperate to sub-Arctic or tropical operation.

CONCLUSIONS

Weighing all the foregoing facts, it may be concluded that if certain military aero-engines are developed expressly for troop transports and long-range reconnaissance aircraft, these engines should be quite suitable for use in civil aircraft. If, however, all research and development resources are concentrated on engines primarily for fighter aircraft (as well they may be in times of retrenchment and economic crises), and attempts are made to modify these engines to make them suitable for other duties, then it is unlikely that civil aviation will be able to use them economically.

The best policy would appear to be to split the development resources into two sections; the first developing high performance engines for use in fighter aircraft; the second developing engines especially for civil aviation. In time of war, the civil engines could then be switched to transport applications, for which they would be admirably suited, and to heavy bombers (if any).

Looking farther ahead, to the era of guided projectiles, it would seem that the need for fighters and bombers as we now know them may disappear altogether. The types of power plant suitable for guided projectiles will be very different from anything which can be used for civil aviation, and there should then be no temptation to try to make either type suit the other's duty.

REVIEWS

JANE'S ALL THE WORLD'S AIRCRAFT. 1949-50. Compiled and edited by Leonard Bridgman. Sampson Low, Marston and Co. Ltd., London. £3 3s. 0d. net.

"Jane" has a new three-column dress which makes her look more up-to-date than ever, and younger despite her forty years. Yes, it was forty years ago, in the year Bleriot flew the Channel, that Fred T. Jane first published the annual which is now a lasting monument to his memory.

The editing of *Jane's* is a tremendous task and because of that there is bound to be a delay in giving up to date information as there can also be a delay in removing information which is out of date. The aeronautical sleuth can find both in *Jane's* and some reviewers make a point of doing so. The present reviewer has had considerable experience of preparing matter for publication, as he has of meticulous proof-reading to keep out the inevitable error. This experience makes him say unequivocably that *Jane's* is one of the best edited books of reference published.

That that opinion is not unique can be tested where there is any aeronautical group discussing aircraft or aircraft engines. "You'll find it in *Jane's*" is one of the major prophetic phrases used in aeronautics.

As was to be expected, the British and American aircraft and aero-engine sections outnumber in their pages those of any other countries, the U.S. with 95 pages and 219 illustrations, and Great Britain with 78 pages and 160 illustrations. In proportion to population (as in some aircraft and aero-engines!), however, Great Britain holds a lead which must give considerable satisfaction to—Britons.

In the Aero-Engine section 27 pages out of 86 are devoted to the gas turbine—figures which will soon be reversed. The remarkable advances made since 1930 when Whittle took out his famous basic patent are shown only too well by the descriptions of the many engines which have been developed from his work.

A first class annual produced in a first class way.—J.L.P.

AERONAUTICAL ENGINEERING. VOLUME I. R. Tatham, B.A., A.F.R.Ae.S. The English Universities Press Ltd., London. 1949. 10s. 6d. net. 173 pp. Diagrams. Index. Appendix.

This book is one of the Technical College Series published under the general editorship of P. Abbott, B.A., and is written to cover the major aeronautical subjects of aerodynamics, aircraft structures and design, to the standard required for the stage 2 and stage 3 courses for the Ordinary National Certificate.

Mr. Tatham is Senior Lecturer in Aeronautical Engineering at Loughborough College, and as such is well qualified to undertake the preparation of a work of this character.

The book may be divided into five sections; the first deals briefly with the historical aspect leading up to present-day aircraft configurations, the second part deals with properties of the atmosphere and carries the reader through the fundamentals of aerodynamic theory and principles of flight. Sections three and four cover the elements of structural analysis and general principles of aircraft design procedure; section five is devoted to the materials of aircraft construction, and to the design of joints, bolt-groups, and so on. An appendix, covering the fundamentals of mechanics, is also included.

The reviewers—themselves lecturers in Aeronautical Engineering—have approached the subject from an instructional angle, and offer the following comments:—

The chapters dealing with aerodynamics are very well presented, although the text is of a fairly elementary nature. These chapters are useful introductions to aerodynamics, and the author could usefully combine the materials contained in this text with his later work to make a good elementary treatise on the subject.

The use of full mathematical treatment, where necessary, is to be commended and is really essential even in an elementary text.

The air flow photographs, on pages 39-42, are well suited to the text, but the actual quality of reproduction is poor and should be improved. Since the chapters on structural analysis are written principally for the benefit of National Certificate students they are unavoidably limited in appeal.

One regrets, for example, that information on, say, principal stresses, beam deflections or thin-walled tubes in torsion is omitted. The proof of the relations $M/I=E/R=f/y$ might well have been followed by beam shear stresses. It may be that references to "later stages" imply a fuller exposition in Volume 2.

However, as a preliminary introduction to the vast subject of structural analysis this section is highly commended.

Each of the five sections is admirably set out with clearly defined proofs and easy to follow examples.

The chapter dealing with aircraft materials is of a very elementary nature, but is sufficient for an introductory survey of the subject.

It is felt that the limitations imposed by the author's method of calculating the loads on the bolts of an eccentrically loaded joint should be more positively stressed. Mr. Tatham states quite rightly that the plate is assumed to be rigid and that any distortion which might arise is due to the shear strain of the rivets, but mention should be made of the practical application where deflection of the member to which the fitting is attached will play a big part in determining the direction and magnitude of the loads in the bolts.

Types of socket and plug fittings are included at the end of the chapter, together with methods of calculating the stresses in the fitting and tubes. Illustrations of typical plugs and sockets might be enhanced by the addition of the shoulderless type of plug, the use of which avoids the necessity of extreme accuracy of finish at the end of the tube.

The Appendix is very useful, as an understanding of the fundamentals of mechanics is essential for a work of this nature.

Overall, the layout of the book is good and it ably covers the syllabus that it is designed to meet. The inclusion of photographs of present-day aircraft in Chapter I illustrates well the various configurations likely to be employed, but also tends to date the book.—R.M.H.; D.C.B.; E.J.M.

ATMOSPHERIC TURBULENCE. By O. G. Sutton. Methuen Ltd., London. 1949. Monographs on Physical Subjects. 6s. net. 107 pp.

No systematic treatment of atmospheric turbulence, outside the necessarily condensed limits of meteorological texts, has heretofore existed in the English language. Professor Sutton has now filled the gap, at least in those parts of the subject with which he deals, this being a monograph and comprehensiveness of treatment not therefore to be expected, even if hoped for.

Atmospheric turbulence is without doubt a highly important matter in aeronautics. Terrestrial boundary-layer turbulence is of some concern in aircraft landing and take-off and, indirectly, in determining the incidence of bad visibility and fog. In the free atmosphere the much larger scale turbulence, or gustiness, associated particularly with cumulo-nimbus shower clouds, gives rise to intense smaller scale eddies for which the aircraft has to be appropriately stressed. In the upper reaches of the troposphere and in the lowest part of the stratosphere are to

be found occasional patches of clear-air gustiness, which, even if they give rise to no dangerous stresses, might cause some discomfort to those travelling in the fast high-level air liners of the future. Professor Sutton deals only with the first of these categories, which is understandable, since only in the layer of air near the earth's surface have turbulence phenomena been widely examined and discussed. Moreover it is the sphere in which Professor Sutton has been a leading exponent over the past two decades.

The author's treatment is, wherever possible, mathematical, and had he chosen to "go higher" he would undoubtedly have needed to be more descriptive and to have left much of the mathematics behind him. These restrictions would not, however, be so serious if the treatment of the subject, within the limits imposed, were firmly based on hydrodynamical and thermodynamical procedures. For extrapolation to other conditions might then be made with some measure of success. It is no criticism of Professor Sutton to say that that is not, unhappily, the case. Turbulence still awaits its Clerk Maxwell even for the phenomena which appear in the fluid-motion laboratory. There has arisen, it is true, a more fundamental approach to the subject since Taylor's classical papers in the middle Thirties, but present theory is hardly able, as yet, to advance out of the laboratory and face the more complicated atmosphere with its varying density gradients and larger scales of motion. It may be indeed that the study of the larger scale flow patterns of the atmosphere will yet help to elucidate turbulence phenomena on the laboratory scale.

In the absence of some satisfying physical theory, Professor Sutton shows what may be done by quite empirical means to bind a fairly wide range of phenomena into reasonably coherent form. Having first described qualitatively the features of turbulent flow and summarised the observations made on such flow by earthbound instruments he proceeds to an examination of such theory as exists. The older K (eddy viscosity) theory—a matter of trial and error in the solution of equations—having been quickly dismissed as sterile, the reader is introduced to Prandtl mixing length theory and the author's own empirical formulation of the Taylor correlation function, the function which measures the rate at which an eddying mass of air loses its identity. On the latter is erected a quite large body of formulæ dealing with the transfer and concentrations of momentum, heat and matter arising from various classes of source. It looks imposing and is useful within its tried limits. But one might have expected the author to point out the lack of a physical foundation. One finds it difficult in fact to agree with his view that he has chosen for treatment "those parts of the subject . . . . significant for future development."

The book is well written, referenced and indexed, and provides an excellent summary of work which has yet many useful functions to perform.—P.A.S.

RECENT ADVANCES IN RADIO RECEIVERS. By L. A. Moxon. Cambridge University Press, London. 1949. 18s. net. 183 pp. 93 figures. Index.

This is another volume in the Cambridge series of monographs on "Modern Radio Technique" which deal principally with the advances made during the war years. As in the previous volumes, a knowledge of the state of the technique in 1939 is assumed, and after a short introductory chapter the attention of the reader is directed at once to consideration of the problem of noise.

The concept of noise factor and the difficulties which arise in defining a precise and practically useful figure of merit for the signal/noise performance of a receiver, are dealt with in considerable detail. The reader would probably have benefited if less space had been taken up by this discussion and attention concentrated on what is now accepted practice.

The third chapter deals with the design of minimum noise factor amplifiers. Expressions are obtained from the equivalent circuits for the noise factor and

optimum working conditions for triodes in various methods of operation, *i.e.* grounded grid, plate or cathode, and also for a pentode.

The following two chapters deal respectively with the noise factor of mixers and the measurement of noise factor.

Chapter 6 is concerned with I.F. amplifiers and the author rightly points out that the improvements have resulted more from accumulation of knowledge and experience than radically new ideas. He does not, however, draw attention to the consolidation of the position of the single ended R.F. pentode introduced just before the war, and the considerable progress that has been made in the design of compact multi-stage, high-gain amplifiers.

The last three chapters are given to a brief general review and deal in turn with "Trends in practical receiver design," "Some new kinds of receivers" and "Some circuit tricks."

Finally there is a short appendix giving design formulæ for I.F. amplifiers.

It is unfortunate that almost half the book is taken up with one aspect of the noise problem, and so little space is found for other subjects, such as transmission line R.F. circuits, in the use of which considerable advances have been made. It is also to be regretted that the experimental results quoted for British valves relate to types which are already out of date.

The book is clearly written, with apparently few errors, and includes a large number of figures which greatly assist in the following of the text.—C.P.F.

THE OBSERVER'S BOOK OF AIRCRAFT. By Joseph Lawrence. Frederick Warne and Co. Ltd., London. 1949. 4s. 6d. net. 256 pp. 370 illustrations. Index.

One of the less satisfactory of the many wartime books on aircraft recognition has now appeared in a new and considerably revised edition. It has been greatly improved. Not only has the original unattractive title of "Airplanes" been dropped, but the previous outline drawings have almost completely given way to far more appropriate photographs and silhouettes—the latter largely from that now defunct journal, *The Aeroplane Spotter*.

The majority of more important contemporary aeroplanes, helicopters and gliders are now covered, but there are still numerous tedious inaccuracies. In any further edition these should be eliminated. Performance figures and other characteristics quoted ought to be rationalised. Cruising speeds need relating to a power, aircraft weight and operating altitude; at least the empty and maximum take-off weights should be stated. The day has passed when reference books can usefully quote a few unrelated performance parameters. Unfortunately some of the best-known continue to do so. They must mend their ways. If this little book can do the same, it will meet a real need.

Meanwhile, the present edition is a useful—if not entirely reliable—pocket-sized reference book which will appeal to the young air enthusiast and to those still concerned with aircraft recognition.—P.W.B.

AIRCRAFT MAINTENANCE AND REPAIR. By the Technical Development Staff of Northrop Aeronautical Institute. McGraw-Hill Book Company, Inc., New York. 1949. $6.00. 444 pp.

This text book is a welcome addition to the aeronautical library and should be of great assistance to personnel in all departments of the Aircraft Industry, dealing with inspection, maintenance, repair, overhaul and operation of aircraft. It contains a wealth of useful basic technical information illustrated by photographs and drawings and written in a simple, easy to follow, manner with the subjects so arranged to be of the greatest value to teachers engaged on aeronautical instruction and to the individual intent on self improvement.

Among the variety of aeronautical subjects dealt with are the fundamentals of hydraulics and systems which are fully explained in detail, are well written and admirably illustrated. Gas welding technique, equipment and repair is also extensively covered over a number of chapters. Useful information is given to the welder on identification of metals by means of the spark and chemical tests, but this should only be resorted to under exceptional circumstances, when specification information is not available. In this country, the welder must demonstrate his ability by passing the standard aeronautical inspection test, but apparently in America this is not necessary. A short paragraph on spot welding with the electro mechanique welder would have been appreciated.

Heat treatment and inspection of metals is an interesting and useful chapter but it is suggested that the contents of the liquid bath could have been included.

Layout work, its purpose, drawing instruments, geometrics and bending allowances with tables have been fully explained. Riveting and recommended riveting repairs are excellent chapters on the fundamentals of riveting, and procedure in general, and are well illustrated with repair scheme drawings, but the inclusion of a paragraph on duralumin rivet heat treatment and control would have been helpful. The construction and repair of wooden aircraft is another well-written chapter and the subject is completely covered. The chapter on fabric covering and dope application gives the fullest information on both subjects.

An excellent chapter on wire and cable work includes a fine demonstration of cable splicing by photographs. The difference between assembly and rigging is clearly defined in another good chapter, and the last chapter, dealing with weight, balance and loading, is well constructed and explains the simple basic principles.

Personnel engaged on instruction, maintenance and repair of British-designed and constructed aircraft must use, wherever possible, the standard approved repair schemes, and also comply with the Aeronautical Inspection Department's and Air Registration Board's requirements. For the British edition of this book, the inclusion of terminology and specification, and American and British comparisons, are recommended.—C.A.M.

ELEMENTS OF INTERNAL COMBUSTION TURBINE THEORY. H. T. Adams. Cambridge University Press. London, 1949. 16s. net. 163 pages, and 12 pages of appendices. 123 figures and 3 charts.

The author of the "restricted" M.o.S. publication on the aircraft gas turbine has now published a text on gas turbine theory based on the "Blue Book" which will prove a useful addition to the gas turbine literature.

After considerable experience of teaching aeronautical engineers on the Power Jets courses, H. T. Adams sets out in this book to introduce the reader to the theory of the centrifugal and the axial compressor, the gas turbine, methods of stressing components, performance analysis, heat exchangers, and so on. Generally the treatment requires good knowledge of principles if the text is to be read without difficulty. However, readers are assisted by worked examples and there is an introductory chapter on thermodynamics.

Gas turbine progress has been so rapid that theories continue to change, and specialists will not find the work sufficiently complete. It is a book which will be eagerly read by student engineers. The author has had to decide what can be taken for granted so as to get the desired result economically, and explanation of the principles suffers at the expense of a more complete mathematical analysis. It would be dangerous for anyone who had read the book from cover to cover to feel he had mastered the elements of the gas turbine. Practical experience will soon show that at the best the theory is an insecure framework, but it should be one which operating experience will gradually stiffen and then build up.

The sections on axial flow theory include blade design and vortex flow and will prove interesting to aerodynamicist and engineer. Here again those immersed

in this subject will notice incompleteness; for example, the old constant value of the work factor for axial compressor blading is used, whereas it is most important in design to know that it is likely to be considerably greater in the first stage than the last.

Stressing gas turbine components is a subject on its own. The author gives methods of attacking the blade and disc stresses, centrifugal impeller stresses, whirling speeds, and so forth, as well as associated vibration problems.

In the chapter on heat exchangers a few notes are given on the rotating regenerative type, as well as the better known recuperator which is treated in more detail. In appendices there are useful notes on equilibrium running of the compressor turbine pair and on combustion.—A.W.M.

CORRESPONDENCE

COMPRESSION STRUCTURES FOR MINIMUM WEIGHT

In the paper by D. J. Farrar (The Design of Compression Structures for Minimum Weight, November 1949 JOURNAL) it states in paragraph 4.2 (*d*), "We assume that after the skin buckles it has a constant $\frac{df_{\text{AVERAGE}}}{df_{\text{EDGE}}} = 0.3$."

It is not clear whether this means in *every* case or whether a value dependent on the b/t ratio of the panel, as obtained from, say, R.Ae.Soc. data sheet 02.01.03. (Plot of average plate stress against edge stress) should be used.

From this curve it would appear that for $f_{\text{EDGE}} = 20{,}000 - 25{,}000$ lb./sq. in. $b/t = 120$ is necessary to give a slope of 0.3.

The following values for 4 in. and 6 in. panels show that b/t has a considerable effect on the slope $\frac{df_{\text{AVERAGE}}}{df_{\text{EDGE}}}$:—

	← $b=4$ in. →		← $b=6$ in. →	
t	$\frac{b}{t}$	Slope	$\frac{b}{t}$	Slope
22	143	.27	214	.21
20	111	.32	167	.24
18	83	.36	125	.29
16	62	.41	94	.32

William Morse, *Assoc. Fellow.*

MR. FARRAR'S REPLY

Mr. Morse's comment is a constructive one and therefore particularly welcome. I fully agree that over the range of thicknesses and stringer pitches specified by him, which are all reasonably practical, the average stress/edge stress slope can vary from 0.2 to 0.4.

The adoption of a constant value of 0.3 would appear even more of an over-simplification when one notes that the values quoted by Mr. Morse could quite easily be included in the analysis. Referring to paragraph 4.2 of the paper, $\frac{df_{\text{AVERAGE}}}{df_{\text{EDGE}}}$ would now be a function of $\frac{f_{\text{EDGE}}}{fb}$ only, the variation being given by R.Ae.S. structures data sheet 02.01.03. This does not introduce an extra variable, and the general analysis proceeds on the same lines as those already given.

Justification for the omission of this refinement may be found when one considers that data sheet 02.01.03 represents only the average of representative test results. In an experimental investigation of skin buckling undertaken by the writer (S. and T.M. 12/47) the average stress/edge stress slope was found in some cases to reach extremes of 0.5 and 0.1 within the range of practical designs. (The higher value was associated with very robust stringers, the lower value with plastic effects which became important in some cases at edge stresses above 20,000 lb./sq. in). The values quoted on 02.01.03 do not claim to represent more than an approximation to a limited range of designs (a fact of which the reader is warned on that data sheet).

It is worth noting that an error of 0.1 in assessing $\frac{df_{\text{AVERAGE}}}{df_{\text{EDGE}}}$ leads for the optimum designs to an error of about 10 per cent. in the Euler load, and to only a very small error in the edge stress associated with it. This error is comparable with those due to initial eccentricity and to cladding of the sheet, which have also been neglected in the analysis.

It is clear, however, that 02.01.03 gives a good approximation to the behaviour of the buckled skin for a wide range of panels, and optimum design charts can well be based on it. The effects of eccentricity and cladding would still have to be allowed for separately, and care must be taken to check that the designs are those to which 02.01.03 represents a good approximation.

D. J. Farrar, *Assoc. Fellow.*

OPENING BEHAVIOUR AND FORCES OF PARACHUTES

In his paper (Notes on the Opening Behaviour and Opening Forces of Parachutes, November 1949 JOURNAL), Mr. O'Hara has expounded a thesis on which I must take issue. My five years' wartime experience in the control of the testing and technical development of parachute equipment will be well known to most of the authors of his references. I have always been sceptical of the practical value of abstruse mathematical calculations and formulæ in assessing potential parachute performance, partly because I am no mathematician, and largely because these mathematical conceptions are frequently based upon false premises which produce unreal solutions for an item of equipment notorious for its vagaries in performance. At the expense of being labelled "reactionary," I persist in my contention that the only proof of the parachute is in the dropping, and the only positive method of ascertaining even approximate performance is to "make 'em, take 'em up, and drop 'em," the more the better.

The Airborne Forces Experimental Establishment and the Royal Aircraft Establishment did not indulge in parachute technical development to any appreciable extent until late in 1941 or early 1942, although several (largely theoretical) reports had been compiled by the R.A.E. before that date. Their subsequent experience in the practical field refuted (as they will probably agree) many of their theoretical conceptions, and for that reason any papers published during or before 1942 from this source must be suspect. This applies to References Nos. 4, 5 and 7; I had an active hand in the refutation of Nos. 5 and 7. Reference No. 6 was proved to be largely misconceived in subsequent tests, while parachute information from German sources, which I assume to apply to Reference No. 3 (Scheubel), had in many cases been proved erroneous previously by our own development tests, and this must therefore also be suspect.

On Reference No. 1 Mr. O'Hara presumably bases much of his paper, and as I question the validity of this, I also question the reference. I am not familiar with References Nos. 2 and 8, but as they were both apparently published when I was most actively engaged in work involving their conclusions, I can only assume that they were not sufficiently important, or sufficiently authentic, to warrant my attention. I might add that the most successful contribution of the R.A.E. to the test programme was its provision of nose, tail, and ground-to-air high-speed cameras—and their operators—for photographing the thousands of practical operational drop-tests made under my direction. It is perhaps significant that, among the references quoted, no names appear from the half dozen or so R.A.E. and A.F.E.E. officers most actively engaged in parachute technical development. It might be deduced from this that these active participants realised the dangers of committing parachute theory to paper for posterity, profited from my precepts on the subject—or were too busy getting on with the job to compile complex reports.

I do not propose to criticise the mathematics of Mr. O'Hara's paper; my only real venture into this field was the evolution of an empirical formula for rate of descent which worked, and was used by the R.A.E. in preference to their own formula which was mathematically and theoretically correct, but gave the wrong answer in practice. I will not cite in this connection the incident of the jeep which was dropped with disastrous results because it carried only half the necessary spread of parachute. This was not directly the fault of the R.A.E. formula, but rather of the R.A.E. official who forgot to multiply by two!

I have to assume that the A.F.E.E. and R.A.E. now have accurate and efficient instruments for checking the force of opening, which is presumably what we practical men have known for years as shock load of opening. Apart from this, I must list the assumptions to which I have the strongest objections, and upon which Mr. O'Hara bases his formulæ.

(*i*) Page 1,054 and Fig. 1: Shape for analysis of "force of opening"—flat head and straight sides. This must be an impossibility, unless we return to the pioneer practice of making part of the canopy of tin(!), but it is not even an approach to the shape. This, I might remind Mr. O'Hara, is called a "squid" shape *because* it is shaped like a squid, which, as far as my natural history goes, does not have, and never has had, a "flat head and straight sides."

(*ii*) Page 1,054: "Assume an infinite number of lines." This is, as I have always held, an absurdity, because this would imply a "wall" of lines from load to periphery, and the resultant "parachute" could not, in fact, open at all, and would therefore have no force of opening.

(*iii*) I see no mention of vent or its effect. Perhaps we have to ignore this also, or perhaps practice has returned to the pet R.A.E conception of a shaped canopy with no vent. I had the privilege of testing the earliest specimens of these which, said their progenitors, took account of "hoop tensions," "pressure across the fabric," etc. (although these parachutes would, apparently, have been even better in prospect with an infinite number of lines)—the fact that they unanimously

split across the crown on the first minor test was vigorously disputed as an impossibility until these gentlemen had seen the results for themselves.

(*iv*) Any force of opening tests made in wind tunnels cannot be valid, because this implies a steady air flow, use of a small model parachute, and does not take into account snatch loads, relative horizontal air flow due to aircraft speed, or the very pertinent combinations of speed, density effect, humidity effect, and so on.

(*v*) Page 1,056: If Mr. O'Hara "stiffens the hem with cord," how does he pack the parachute conveniently or conventionally?

(*vi*) Page 1,056: The assumption is made that the excess fabric between the lines takes the form of indents. This is not true, as any observation of an actual drop, or examination of a film, will show—it is impossible to state whether there is more excess fabric inside or outside the opening canopy, particularly in view of the method of folding it for packing.

(*vii*) Page 1,056: This quotes an example of an inflated canopy being at a speed *higher* than the critical velocity. This cannot be true if the canopy is fully inflated—in practice the canopy would probably split under these conditions, and would collapse *for this reason*, which is not by any means equivalent to squidding.

(*viii*) Page 1,057: Is the same fabric rendered "relatively stiffer" if the canopy size is reduced? If so, from whence does it gain its greater relative stiffness?

(*ix*) Page 1,057: This page quotes a canopy with parallel rigging lines; this is just as feasible as making it with an infinite number of lines—except, in this case, they probably stretch to infinity. "The elasticity of the system" is ignored—canopy, line, and suspension materials are all normally highly elastic (otherwise they split or break) and surely this is one of the most important attributes to consider with effective force of opening. A "non-porous canopy" would not, in fact, function along the lines on which Mr. O'Hara has based his deductions, for it would open with a crack and either split or part with its load, irrespective of its number of lines, or whether they were parallel or not.

(*x*) Page 1,059: How is the basis of a "flat disc" reconciled with the "flat top and sides" used as an example earlier?

(*xi*) Page 1,060: How long has it been the practice to state the rate of opening in terms of ft./sec.? I can understand, but not condone, using the speed and distance fallen during development as the factor, but surely the figure of "up to 16 ft./sec." at sea level would then be wrong. The rate of descent of a canopy fully inflated is greater than this, and a parachute with load descends far faster while opening than it does when fully inflated.

(*xii*) Page 1,060: The difference between rate of opening, in any terms, at high altitude and sea level is surely exagerated, and I cannot agree with the conclusion nor the deductions for an *increase* in the force of opening at high altitude. I have in my possession an English, or rather American, translation of a Russian technical report whose conclusions, based on the Russian premises, and proved mathematically, are diametrically opposed to those of Mr. O'Hara. Throughout his paper, no definite mention is made of canopy size, but a load of 200 lb. is quoted, so I assume a 28 ft. diameter, or equivalent, parachute. If Mr. O'Hara's conclusions were true for this force of opening increase with altitude, a pilot baling out, either normally or by seat ejection, from a fast, high-flying fighter, with immediate release of a standard 24 ft. diameter canopy, would either crack up his parachute, his lift-webs, or himself, and we know that this does not, in fact, occur.

In the whole of the paper, no indication is given of the fabric considered, which may be silk, nylon, rayon, and cotton of many different specifications, or of rigging lines, which may be silk, silk-nylon, nylon, rayon, flax, and so on, and all of which will give entirely different results in different combinations; nor are we told whether the canopy is flat, shaped, lobed, with skirt, and so forth. This is like giving anticipated performance calculations for an aircraft the type or class of which is not stated. Even in the vague bases and invalid premises which Mr. O'Hara has given

us, no numerical or practical conclusions are reached, and there is no conceivable use for purely academic and exact results on a type of equipment whose actual performance varies between the widest limits, so that the only reliable data of any value is based on the mean of a large number of observed drop-tests.

Parachutes have always been made stronger than is strictly necessary, but any reduction in size or weight of the components to conform to exact calculated values for force of opening would be negligible in any case, and would probably result in occasional, or frequent, failure.

S/Ldr. H. R. Bunn, M.B.E., *Associate.*

Mr. O'Hara's Reply

It is clear that S./Ldr. Bunn and I have somewhat different views on the use of theoretical work in parachuting investigations. S./Ldr. Bunn appears to have a conviction that parachutes are not a suitable subject for theoretical analysis. This conviction I do not share; on the contrary, I suggest that even approximate theories of the type given in my paper can assist in the understanding of the way in which parachutes operate, and so lead to the development of more accurate theories and to general improvement in parachute design.

S./Ldr. Bunn's letter contains many mis-statements and misinterpretations, and a detailed reply would become intolerably long; I shall content myself, therefore, with a few comments only.

(*a*) The photographs of squidded parachutes in Reference 2 (R and M. 2119) and Reference 3 (now R and M. 2324) are well worth study; they show that the simple theoretical shape assumed is, in fact, a fair approximation to that of a squidded parachute. Incidentally Professor Duncan's paper (Reference 2) is one of those S./Ldr. Bunn assumes "not sufficiently important, or sufficiently authentic" to warrant his attention.

(*b*) S./Ldr. Bunn disputes the increase in opening force with altitude and suggests that if this were true, damage would occur to the parachute or man, and states that we know this does not, in fact, occur; I do not know what evidence he has for this statement, but according to American tests, this is exactly what, in certain circumstances, does occur.

(*c*) He complains that no indication is given in the paper of the fabric or of the type of parachute for which the performance is analysed. It should be evident that, as in the case of aircraft, the specification of the parachute for performance purposes can be made in terms of the dimensions and of the aerodynamic characteristics. The distance, R, from the hem to the apex of the canopy is stated in the example given to be 15 ft. The aerodynamic parameters are h, K and L; the canopy fabric is specified by the porosity q. The elasticity of the system is specifically neglected but it is thought that its effect on the canopy opening forces is small; elasticity has an important effect on the initial snatch force, but this occurs before the canopy starts to open out and is only briefly referred to in the Introduction to the paper.

(*d*) It may be seen by comparison with the critical speed analysis that in the opening forces analysis the parachute is implicitly assumed to have an infinite number of lines. (I wonder if S./Ldr. Bunn will be convinced by the explanation that these are mathematical lines only and do not interfere with the air flow?) If the force theory were generalised for a finite number of lines the shape of the fabric indents round the mouth would introduce an arbitrary element which could account for the scatter obtained in observed parachute behaviour and opening forces.

F. O'Hara.

THE SERVICING OF AIRCRAFT

Modern aircraft will eventually obtain modern servicing when the ideas discussed in Mr. Crawley's paper (The Servicing of Aircraft; Choice of Principle and Procedure, December 1949 JOURNAL) have borne fruit in practice. It emphasises the importance for further thought, in design for maintenance, which will help to reduce uninspectability and cost to a minimum by better accessibility in first-line servicing, should a part fail under its estimated service time.

There are instances of British gas turbines running 500 hours without attention or any appreciable wear being apparent on strip examination; this reveals that many more hours, probably 1,000, would have been justified, in which case the turbine should fly 500 hours with just a short inspection before flights, provided that the pilot has not reported defects after the last flight.

Part 4 of the paper mentions collecting information on predictability and inspectability from service organisations, but it is desirable also that a sense of urgency be instilled into the handling of defect reports—as Mr. Greenwood emphasised in his paper (Aircraft Defect Report Procedure, November 1949 JOURNAL).

I assume that in planning servicing procedure for unpredictable and uninspectable parts, the only procedure would presumably be to take into consideration material specification, stresses, fatigue of the material, and limits used in manufacture and assembly, the valuable reports from service or airline organisations of the behaviour of the parts under flying conditions being the deciding factor.

H. C. Bevis, *Associate.*

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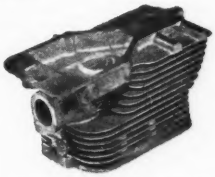

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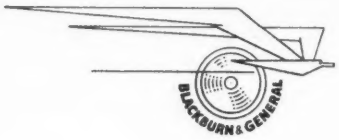

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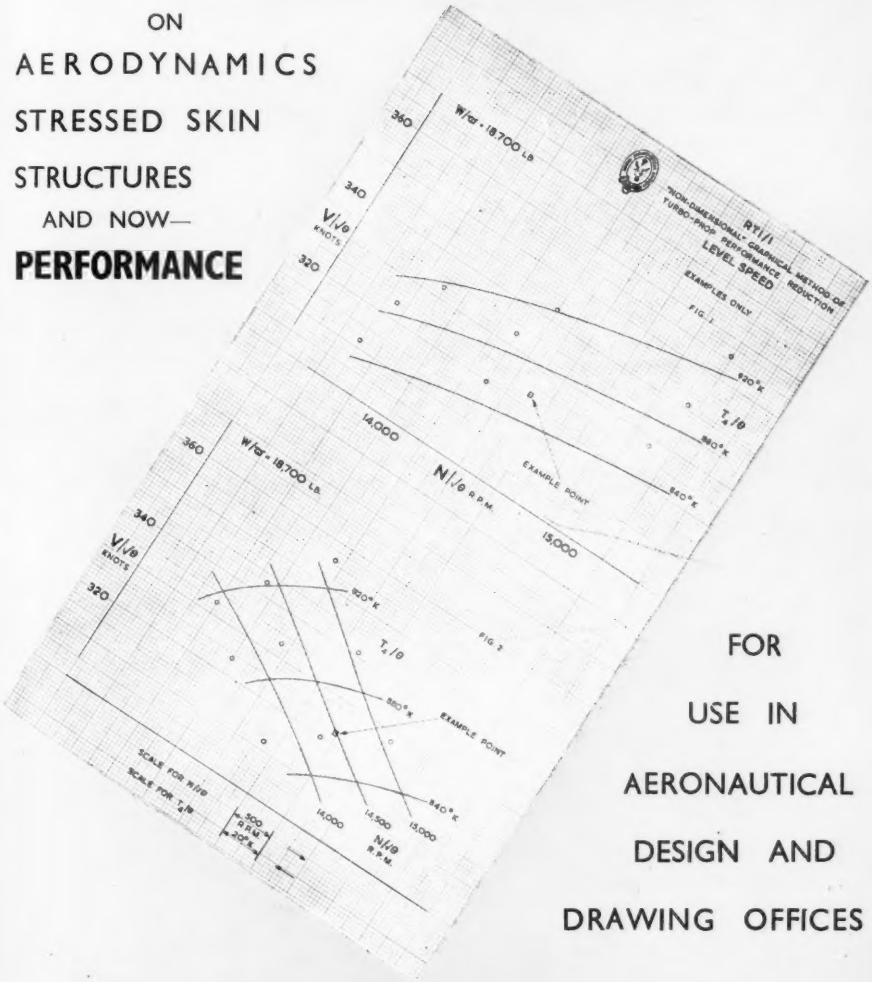

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